DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 200

AN INVESTIGATION OF OXYACETYLENE WELDING AND CUTTING BLOW-PIPES, WITH ESPECIAL REFERENCE TO THEIR DESIGN, SAFETY, AND ECONOMY IN OPERATION

BY

ROBERT S. JOHNSTON, Engineer Physicist
Bureau of Standards

DECEMBER 28, 1921

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AN INVESTIGATION OF OXYACETYLENE WELDING AND CUTTING BLOWPIPES, WITH ESPECIAL REFERENCE TO THEIR DESIGN, SAFETY, AND ECONOMY IN OPERATION [1]

By Robert S. Johnston

ABSTRACT

Apparatus from 14 of the most prominent manufacturers were tested under standardized conditions, the practical work of cutting and welding being carried on by a group of experienced welders and cutters directly under the supervision of the Bureau representative.

None of the commercial cutting blowpipes procurable appear to be designed according to definite theory. None of the cutting blowpipes are efficient in cutting metal of all thicknesses. Considerable improvement can be made in economy in cutting 2-inch metal and possibly in other thicknesses. About 12 inches is probably the maximum thickness that may be cut economically with oxyacetylene blowpipes.

None of the welding blowpipes were correctly designed, and none were free from flash-back phenomena. Most of them are somewhat unsafe and inherent defects in design result in unsound welds. With a properly designed welding blowpipe, it is believed that satisfactory fusion welds may be made.

CONTENTS

[1] The paper presented herewith is the result of a special investigation conducted at the Bureau of Standards for the War Department, as represented by Maj. A. B. Quinton, jr., tank, tractor, and trailer division, Ordnance Department, through which department the results of the investigation have been made available for public distribution.

I. INTRODUCTION

1. PURPOSE OF THE INVESTIGATION

During the war period oxyacetylene welding and cutting equipment became of primary importance to the American Expeditionary Forces as a means of demolition or field repair of various engineering structures. The increased use to which this apparatus was put necessitated the purchase by the Government of a large number of sets of welding and cutting equipment. Investigation showed that there were no reliable data available upon which specifications for this equipment could be based.

After several conversations between representatives of the War Department, members of the Bureau staff and representatives of the oxyacetylene blowpipe manufacturers, the Bureau of Standards received under date of September 14, 1918, over the signature of Capt. H. Carlton, miscellaneous section of the Ordnance Department, a letter requesting, in the name of the Chief of Ordnance, that the Bureau of Standards make a test to determine the "efficiency, safety, and workmanship entering into the several makes of apparatus" (oxyacetylene).

2. HISTORY OF DEVELOPMENT OF THE TESTS

In compliance with this request, a preliminary investigation was inaugurated in cooperation with various divisions of the Army and with the assistance of blowpipe manufacturers to plan tests which should indicate the relative merits of various blowpipes. The investigation originally contemplated an immediate testing of equipment and therefore would have been confined to a short series of rough tests. The armistice removed the urgency of the investigation and the rapidly changing personnel delayed it still further. The delay, however, allowed the scope of the investigation to be extended, and finally a thorough and comprehensive series of tests was developed.

The tests were finally specified after consideration of all suggestions from the various divisions of the Army and Navy and from the manufacturers who submitted apparatus for test. In planning the tests, care was taken to eliminate, as far as this was possible, any discrepancies due to the personal equation of the operators.

In their final form the tests were approved by a majority of the manufacturers, but two manufacturers were dissatisfied and withdrew the apparatus they had submitted for test. In these cases their apparatus was purchased in the open market and tested under the same conditions as the rest. When the schedule of tests had been prepared, a preliminary series of tests was run and the test procedure modified wherever it seemed advisable. The final schedule of tests which was then sent to the manufacturers was adhered to throughout the whole series. The conditions under which the manufacturers submitted their apparatus are given below.

3. STIPULATIONS GOVERNING THE CONDUCT OF TESTS

The stipulations forwarded to the manufacturers were as follows:

The investigation will include:

1. Tests of welding torches.
2. Tests of cutting torches.
3. Tests of regulators.
4. Tests of oxyacetylene welded specimens.

Throughout this series of tests the following conditions will be adhered to:

Gas:

1. All gas used will be of the same analysis within commercial limits.
2. Throughout the series of tests the gas consumed will be drawn from a bank of tanks so that its properties may be as uniform as possible.
3. Identical equipment in the gas lines will be used in all tests.

Torches:

4. The torches will be operated throughout the series of tests in accord with the instructions of the manufacturers.
5. The torches will be operated throughout the series of tests by one set of experienced welders and cutters who will work under the direction of the Bureau's representative in charge of the tests, except that a manufacturer may make a demonstration test using an operator of his own selection.
6. All makes of welding torches will be put through an identical series of tests. The gas pressures will be controlled by one set of gas regulators selected for this purpose.
7. All makes of cutting torches will be put through an identical series of tests. The gas pressures will be controlled by one set of gas regulators selected for the purpose.
8. All cutting tests will be made by mechanical guidance and control of the cutting torch.

Test material:

9. The material used for test purposes consists of ½ inch, 2-inch, and 6-inch steel, each of known chemical analysis.
10. One grade of welding rod of known chemical analysis will be used for the welding tests.

Submittal of apparatus:

11. Any apparatus not voluntarily submitted for test by the manufacturer may be purchased in the open market and tested.

Information concerning tests:

12. Information concerning the tests to which the torches are to be subjected will be made available to the manufacturer before the actual testing is started. All apparatus voluntarily submitted for test must be in the Bureau's hands before the information concerning the tests is given out.
13. A copy of all data obtained during the test of a particular make of apparatus will be furnished the manufacturer of that apparatus.

Witnessing tests:

14. The tests on any particular make of apparatus may be witnessed by three representatives of the manufacturer of that apparatus.
15. Whenever the manufacturer's representatives are present they shall specify in writing that the apparatus tested is of their own manufacture, that it is identical in all respects with the torches of similar style sold under their name in the open market, that it was in proper working order at the beginning of the test (it shall be tried out by a competent representative of the manufacturer before this statement is made), and that the tests were carried out in accord with the schedule made available to them.

Retest and demonstration:

16. Any objections to the methods and procedure in operating the torches during the tests shall be submitted in writing within 24 hours after the completion of the test on any make of torch.
17. When conditions seem to warrant it, the Bureau may make such retests as it deems advisable or necessary.
18. When in the opinion of the manufacturer of a torch he can demonstrate that by the use of his own operators he can produce better results than were obtained by the Bureau of Standards' operators, such a demonstration test will be permitted, provided the manufacturer supplies the material to be used and further, holds himself responsible for all cost necessary in connection with the making of a demonstration test.

Retest and demonstration—Continued.

19. If the opportunity to make a demonstration test is accepted by a manufacturer, such test must be made at the Bureau under the identical conditions, except for operators, in which the Bureau's test was made. Further, the same torches and identical material are to be used for both tests.
20. The Bureau will endeavor as far as possible to assist the manufacturer to secure material of identical composition for demonstration tests.

Decisions:

21. Final decision upon any questions which may arise in regard to these tests will be made by a committee composed of one representative of the U. S. Army, one representative of the U. S. Navy, and three representatives of the Bureau of Standards.

4. ACKNOWLEDGMENTS

In connection with the development and completion of this investigation, the general experience of a number of people was freely drawn upon so that the question might be viewed from its broadest aspects, and such assistance is here acknowledged with the realization that the successful completion of the investigation was largely due to the splendid cooperation received. In this connection the assistance of the following is acknowledged:

The Ordnance Department of the War Department, U. S. A.; U. S. Naval Gun Factory, Washington, D. C.; Hull Division, U. S. Navy Yard, New York; and various manufacturers of oxyacetylene equipment, especially the Davis-Bournonville Co. and the Commercial Acetylene Co. Of the Bureau staff, G. M. Deming and his assistant, L. R. Sweetman, to whom the successful design, calibration, and operation of the testing equipment are largely due, and S. W. Miller, consulting engineer, Rochester, N. Y.

II. DESCRIPTION OF EQUIPMENT USED IN TESTING THE BLOWPIPES

In general the equipment used for making the tests may be listed as—

1. The weighing system for determining the amount of the gases used during the tests by loss of tank weight.
2. The gage-board system containing the necessary pressure gages, regulators, and orifice flow meters.
3. The welding table.
4. The cutting table.
5. The flash-back and safety testing apparatus.

A general view of the entire equipment and its arrangement is shown in Fig. 1. For purposes of analysis and explanation it

may be more easily studied by reference to a diagrammatical sketch, Fig. 2.

Reference to Figs. 1 and 2 will show that the tanked gases were "banked" and suspended by means of a hanging platform from

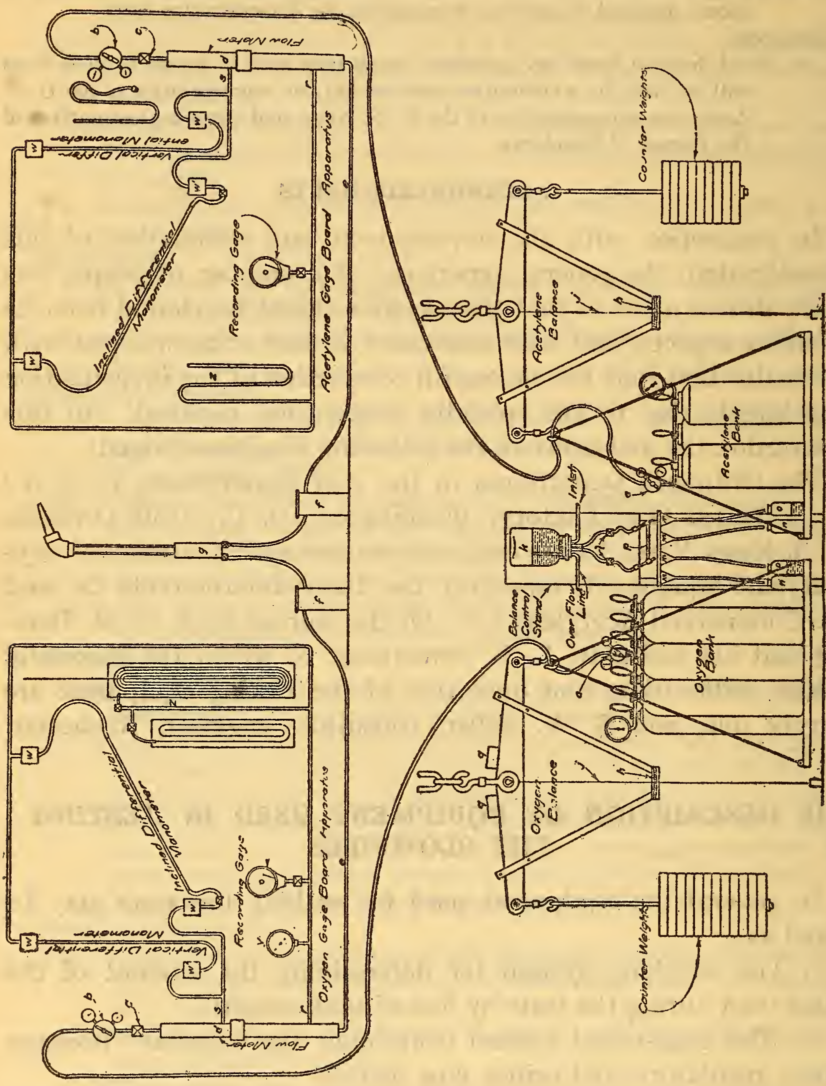

FIG. 2.—*Diagrammatical sketch of equipment and its arrangement*

one arm of an equal arm balance, their weight being counterpoised by dead weights suspended from the other balance arm.

The gas from the tanks on the balance passed through a regulator (*a*) thence through a flexible hose to the back of the gage board. Passing through the gage board the supply line entered a second regulator (*b*) thence through a needle valve (*c*) to the

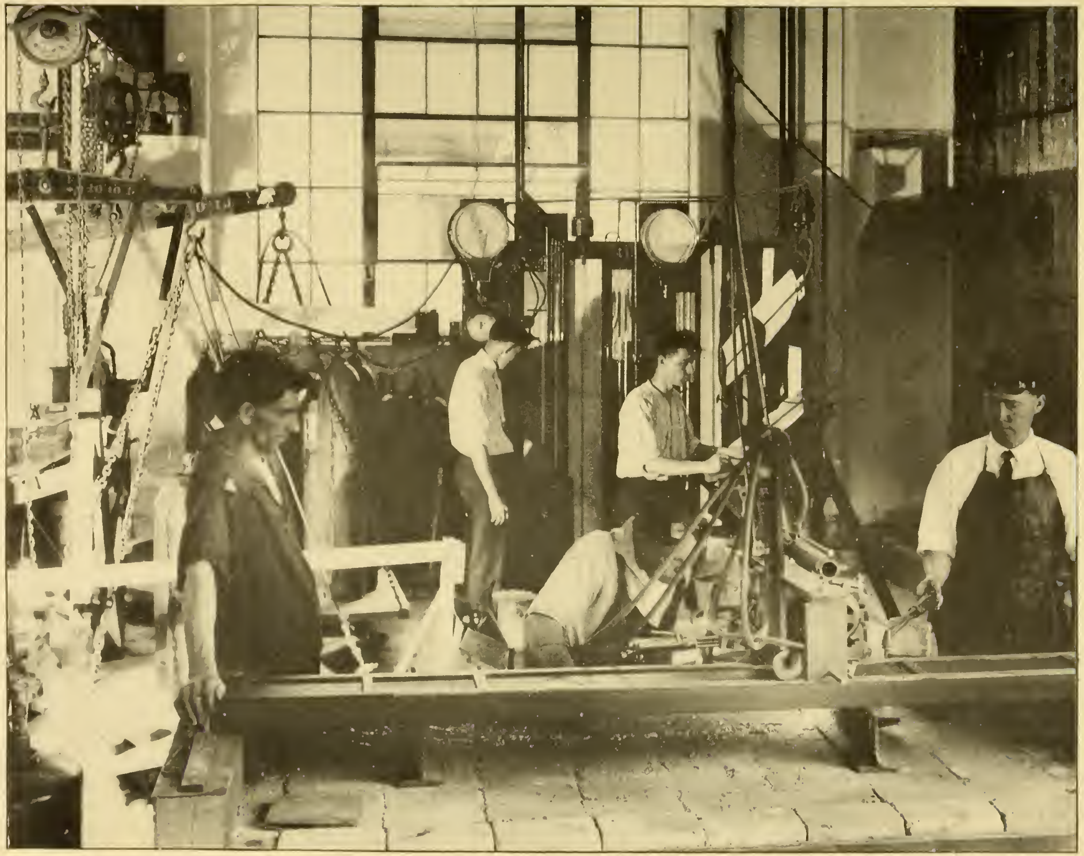

FIG. 1.—*General view of equipment and its arrangement*

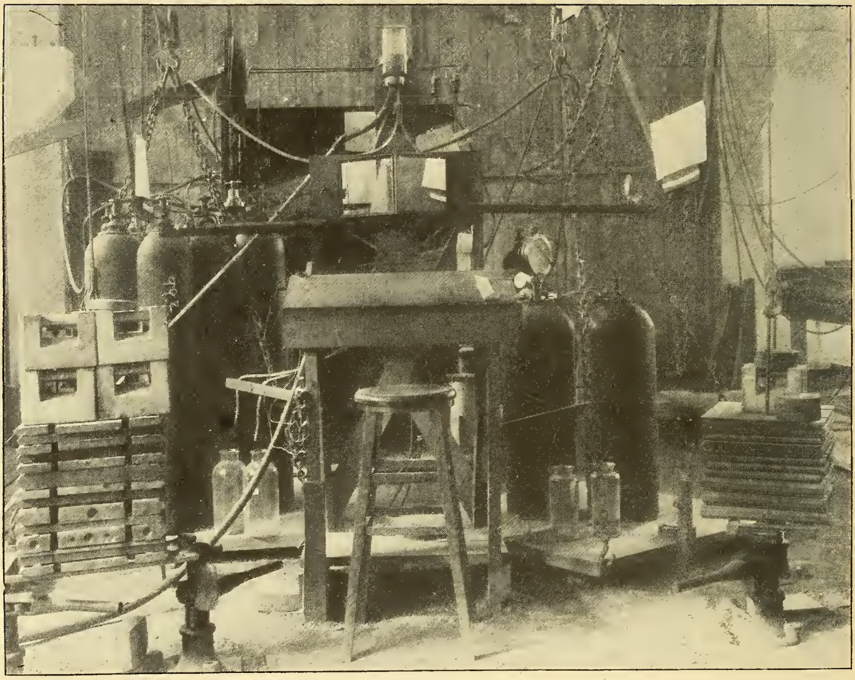

FIG. 3.—*Weighing apparatus showing banked gas tanks on balances and observer's table*

top of and through an orifice flow meter (*d*). The gas coming from the extreme bottom of the flow meter was then conducted through a standardized length of flexible hose (*e*) containing a safety flash-back tank (*f*) to the blowpipe to be tested.

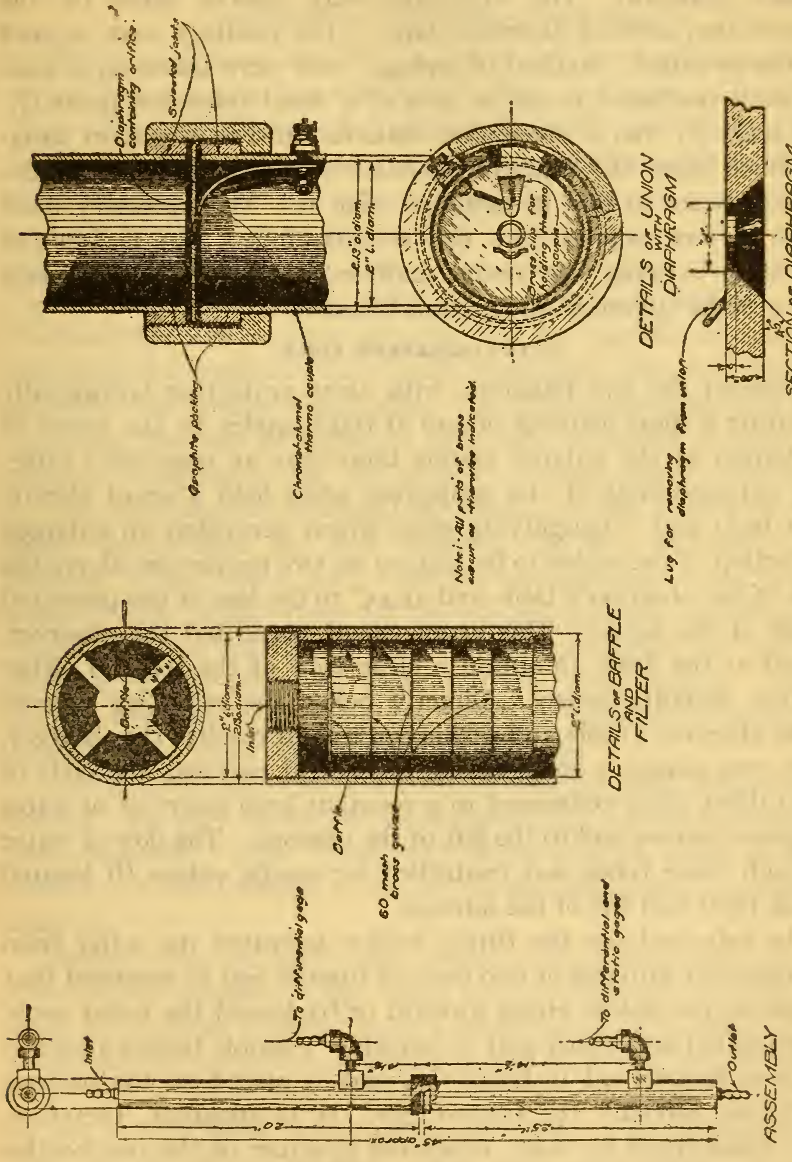

Fig. 4.—*Details of the orifice flowmeter*

1. THE WEIGHING SYSTEM

The weighing system comprised two equal-arm balances of 3000 pounds and 1000 pounds capacity, respectively, for the oxygen and acetylene and the observer's table. (See Fig. 3.)

(*a*) THE BALANCES

The "banked" tanked gas was set on a platform suspended from one arm of the balance. Dead-weights were hung from the other arm of the balance to counterweight the load of the suspended platform. The weighings were always made by the substitution method described later. The readings were secured by the so-called "Method of swings" and were taken on a scale (*h*) as it oscillated to either side of a fixed reference point (*j*). The scale (*h*) was a centimeter scale fastened to a support hanging down below the beam of the balance and rigidly fixed to the balance beam so that it oscillated with it. The necessary fixed point (*j*) was secured by a fine wire stretched taut in front of the scale between the center knife-edge support of the beam and a stake driven in the ground beneath.

(*b*) THE OBSERVER'S TABLE

Between the two balances, with arms projecting horizontally to within a short distance of and at right angles to the plane of oscillation of the balance beams there was an observer's table. The extreme ends of the projecting arms held a small electric light bulb and a magnifying glass which permitted an enlarged projection of the scales to be thrown on two mirrors set above the desk of the observer's table and at 45° to the line of the projected image of the scales. This arrangement permitted the observer, seated at the desk, to obtain a clear view of the scale of either balance instantaneously. Directly below the reflecting mirrors of the observer's table, and within convenient reach of the observer, there was placed a small tilting holder (*p*) carrying the ends of soft rubber tubes connected to a constant level reservoir of water (*k*) placed above and to the left of the mirrors. The flow of water through these tubes was controlled by needle valves (*l*) located to the right and left of the mirrors.

The tube ends on the tilting holder deposited the water from the reservoir into one of two pairs of funnels (*m*) so arranged that by tilting the holder either forward or backward the water could be deposited into either pair of funnels. Flexible tubing attached to these funnels led to bottles (*n* and *o*) placed on the balance platforms carrying the tanked gas. It is apparent, therefore, that water could be easily deposited in either of the two bottles on the balance platforms by simply tilting the tube holder backward or forward. Control of the rate of flow of the water was readily governed by the needle valves (*l*). An observer sitting at the desk and watching the swing of the balance arms could by

simple adjustment of the needle valves permit water to flow into the bottles on the balance platforms at such a rate as would approximately compensate for any loss in weight due to the withdrawal of gas from the tanked cylinders.

(c) METHODS OF DETERMINING WEIGHT DATA

With the necessity of using gas until the blowpipes were properly adjusted before commencing any test operation and because there were two balances to observe as nearly simultaneously as possible at the start of each test, it was not possible to always start the tests with the balance scales at an exact zero. There was a constant and regular "drift" of the zero position as gas was withdrawn from the tanks. Any error from this possible source was readily and easily compensated for as follows: After the blowpipe was properly adjusted and the gage-board observers and practical operators were ready to begin a test, the weighing observer was notified by signal. The latter meanwhile had been adjusting the flow of water to such rate as would as nearly as possible compensate for the weight of gases being withdrawn. At the sounding of the signal he began a series of five turning-point observations for each balance, the five for the oxygen balance being taken first. At the completion of the fourth turning-point observation for the oxygen balance a preliminary warning signal was given, and at the completion of the fifth observation the signal to begin the test was sounded. Immediately following this signal the weighing observer took the five turning-point observations for the acetylene.

The mean of each consecutive three turning-point observations for each gas gave three determinations of the zero of the balance. From these the "drift" of the zero of the balances could be determined and the readings corrected to the actual time of starting the test.

During a test the zero of the balances was maintained as nearly constant as possible. The exact value could not, however, be held for so long a period as the tests required, so that at the completion of a test the zero usually had shifted to one side or the other of the initial zero determination, because either too much or not enough water had been permitted to enter the gas weight bottles on the scale platforms. Such errors were readily corrected, however, by the determination of the final zero.

In order to make this correction it was necessary to determine the sensitivity of the balance. As this did not remain constant

from day to day, the sensitivity was determined each morning before beginning the day's tests. It was desirable to release the load on the balances each evening, but a complete release of the load was found to cause erratic changes in the sensitivity. To avoid this the greater portion of the load was relieved by jacks placed under the counterweights, allowing enough weight to remain to prevent displacement of the knife-edges. With this procedure erratic results from the determinations for sensitivity were very infrequent.

The sensitivity was determined by taking turning-point observations for the zero of the balance oscillations and then determining by the same method the "drift" caused by placing a standard 10 g weight on the counterweight side of the balance. The amount of drift in centimeters divided by the number of grams used to cause such displacement gave the weight equivalent value of the scale divisions in grams per centimeter. This determination was always made with the gas line leading to the gage board "flooded" under a pressure equivalent to the average gas pressure generally used; that is, 125 lbs./in.^{2} for the oxygen line and 20 lbs./in.^{2} for the acetylene line.

During the course of the experiments it was thought desirable also to make one other correction for error in balance determinations. It is almost impossible to stop all leakage when a series of tanks is banked as in these tests. Small leakages in tank valves, too small to be readily detected, were found to exist. To compensate for these the gas lines were flooded as far as the regulator on the gage board and the zero-point determinations made over a period approximating a half hour. The determination of the amount of drift thus found in connection with the weight equivalent value of the scale divisions gave an index of the rate of loss of gas by leakage. This determination allowed all balance data to be corrected for such loss. (See Fig. 19.) If the gas loss exceeded 0.01 to 0.02 pound per hour, actual testing of the blowpipes was not continued until the leaks causing such losses were located and stopped.

(*d*) PRECISION OF WEIGHINGS

As to the precision of readings obtained by the use of these balances and the weighing system it would seem that, giving due consideration to all disturbing influences, the values obtained for gas consumption are accurate to 0.005 pound, and in most cases are probably much closer.

2. THE GAGE-BOARD SYSTEM

(a) GAGE-BOARD REGULATION

During the preliminary investigation of the equipment to be used for these tests it was found that none of the standard regulators generally furnished with such equipment were satisfactory for regulation purposes, if results of any considerable accuracy were to be obtained. Due to the construction of the ordinary regulator the readjustments for pressure distribution are intermittent and spasmodic and allow of considerable variation in the actual pressures delivered on the low-pressure side of the regulator.

It became necessary, therefore, to devise some means by which a more constant and reliable pressure could be delivered to the line supplying the blowpipes. After considerable inquiry and experimental trial the method shown in Fig. 2 and the various photographs was adopted and as a whole proved extremely satisfactory. The main regulation was accomplished by two regulators used in series, one attached to the outlet of the manifold of the banked tanks (*a*, Fig. 2), and the other placed on the gage board just in front of the inlet to the flow meter (*b*). By means of the regulator at the manifold the tank pressures were reduced to an amount about 50 per cent in excess of the pressures required for the blowpipe, the second regulator being used to reduce still further the pressure to that desired.

The various regulators used were the best of a large group that was on hand, their efficiency being determined by constant trials and observations of the regulators themselves. Through this means a set of regulators selected for their good performance was used as a whole throughout the entire series of tests.

The regulator (*b*) at the gage board was changed as occasion demanded in order to secure as sensitive a regulator as possible contingent upon the pressure which it was required to deliver.

It was found, however, that even with the selection of regulators from the large number on hand, too great a variation still existed in the pressures which would have been delivered to the blowpipe line. A part of this trouble was due to the construction of the regulator, in that the reduction of pressures was accomplished by intermittent and spasmodic action of the regulator. Recognizing this, a set of "rappers" was used which vibrated the body of the gage-board regulator (*b*), the idea being that the constant agitation and vibration of the regulator body would tend to keep

the seat of the regulator floating and therefore secure less intermittent action. These "rappers" were connected in series with a master vibrator located at some distance from the board. The interrupting mechanism of the two gage-board vibrators was short-circuited so that no sparking could be produced at the gage board within a dangerous vicinity of possible gas leaks, etc.

Further experience indicated that the insertion of a small hand-regulated needle valve (*c*) between the regulator at the gage board (*b*) and the flow meter (*d*) secured a decidedly more uniform regulation. The standard procedure throughout the tests, therefore, was to have one of the gage board operators make such adjustment by means of the needle valve (*c*) as from time to time was found necessary to maintain constant pressures in the gas line. After a blowpipe had been properly adjusted and had been operating for a few minutes it was seldom found necessary to make any further adjustment in the needle valve, the pressures remaining as a whole very constant through the tests.

By means of the above arrangement it was readily possible to maintain under most all conditions a pressure varying not more than 0.01 or 0.02 of a pound from the desired amount. The constancy of the regulation obtained may be seen from Fig. 21, which is a copy of an average log sheet, or from Fig. 31, a copy of one of the autographic pressure curves. As a general thing the best regulation obtained was far better than that shown on these figures, although occasionally somewhat poorer regulation resulted.

(*b*) FLOW METER

During the study of the methods proposed for testing the various blowpipes it appeared desirable to secure information concerning the amount of gas used through some independent means other than through the loss of weight of the tanks. It seemed essential that these data should be secured as a check upon possible errors in tank weights and further to permit of instantaneous readings from time to time of the relative amounts of gas being consumed by the blowpipes.

After considerable discussion and study it was finally decided that this information could be best secured through the use of a flow meter. A special orifice flow meter, the general details of which are indicated in Fig. 4, was therefore designed and constructed for this investigation.

Referring to Fig. 4 it will be seen that the flow meter consisted essentially of a brass tube, 45 inches in length and 2 inches inside diameter, which was cut into two pieces at approximately the center of its length and fastened together by a screwed coupling. To the top and bottom ends respectively of the tube in line with its longitudinal axis, an inlet and an outlet nipple were brazed. Two other nipples were brazed to the side of the tube, one a short distance above the split joint at the center of the tube, and the other about 10 inches above the outlet nipple. These led respectively to the differential manometer and to the differential and static pressure manometers.

In order to insure uniform distribution of gas throughout the inlet end of the flow meter there was built into the upper end just below the inlet nipple a cross baffle and a series of four 60-mesh brass screens, as indicated in Fig. 4.

The orifices were of the thin plate, sharp-edged type, and were held in position at approximately the mid-length of the flow-meter tube by the adjustment of the coupling as indicated in Fig. 4. A section showing their shape is also included in this figure. Orifices of this type were selected as they were simple and readily machined to exact sizes. Their continued use throughout the series of tests has shown that they have been extremely satisfactory. A total flow of several hundred million linear feet of oxygen has passed through one of the orifices used on the oxygen flow meter at an average velocity of several thousand feet per minute, and so far as can be detected it has shown no signs of wear or erosion. To substantiate this latter a photograph was taken of this orifice before it was used and after it had been put through the entire series of tests. This photograph does not even indicate any rounding of the corners of the orifice, and the check measurements show also that no enlargement of the opening has taken place.

Experience showed that the number of orifices could be limited to five without undue loss of sensitivity by using, in parallel with the main vertical manometers, adjustable inclined manometers. These water manometers had a relatively high sensitivity and were therefore protected by cut-off valves against excess pressure. (See Figs. 1 and 7.)

Since the rate of flow of a gas is a function of its temperature as well as its pressure and density, it was necessary to measure the temperature of the gas as it passed through the flow meter. In order to accomplish this a thermocouple was built into the

flow meter, its terminals being placed directly below the tube coupling. That it might furnish a reliable index of the temperature of the gas and at the same time be free from any possible effects due to the impingement of the gas upon the thermocouple itself, it was held firmly in place just inside the orifice opening by a spring clip as indicated in Fig. 4. Further, that the temperature readings might be affected as little as possible by disturbing interferences from the outside atmosphere, the flow meters were carefully insulated with wool felt lagging and the oxygen meter was still further protected by being incased in a wooden box. A copper-constantan thermocouple was used for the oxygen meter, and a chromel-alumel thermocouple was used for the acetylene meter.

The thermocouples led to a potentiometer and were connected to a cold junction placed in an ice bath in a vacuum tube.

FLOW-METER THEORY.—The approximate theoretical formula upon which the use of the flow meter was based is—

$V=K\sqrt{\frac{P_a h}{T_a G}}$, in which

V = the rate of flow of the gas in cubic feet per hour at 760 mm mercury pressure and 32° F temperature;

K = the orifice constant;

P_a = absolute pressure corresponding to $P=P+B_p$;

P = the flow-meter static pressure (as measured at r, Fig. 2);

B_p = atmospheric pressure;

h = flow-meter differential as read in centimeters of water;

T_a = absolute temperature;

G = density of the gas.

When the gas is a simple gas of constant density, such as oxygen, the formula may be more conveniently used in the simplified form $V=K'f\sqrt{P_a h}$ where $f=\sqrt{\frac{T_m}{T_a}}$ and $K'=\frac{K}{\sqrt{G}}$, T_m being a standard mean temperature.

The value f generally will never vary greatly from unity, as T_a and T_m are as a rule nearly equal. It is therefore possible to ignore the factor f in approximate computations, with resulting errors probably not greater than 2 per cent.

These formulas can readily be modified so that it is not essential that T_a be measured on any specific temperature scale. This allowed the use of the thermocouple electromotive forces themselves as determined by a potentiometer. For convenience, the relation between the electromotive forces and the oxygen-temperature factor shown in Fig. 5 was developed.

Where the gas is a complex one of changing density such as that drawn from compressed acetylene cylinders which contain varying proportions of acetone, the fundamental flow-meter formula may be written, for convenience, $V = k'F\sqrt{P_a h}$, in which $k' = \frac{K}{\sqrt{G_m}}$, G_m being a standard mean density, and $F = \sqrt{\frac{T_m G_m}{T_a G}}$.

G_m was taken as 0.0750 lb./ft.^{3}, which appeared to be the mean density of the gas as taken from the density determinations mentioned later. The value selected for T_a was identical with that used for the oxygen meter. In this later form the temperature density factor F also ranges around unity, so that, as indicated above, it might also be neglected in approximate determinations. In such cases, however, the results will be more liable to error on account of the varying density of the acetylene. The relations between the density, gas temperature, and temperature density factor F, which were used in the interpretation of the test data, are shown in Fig. 6.

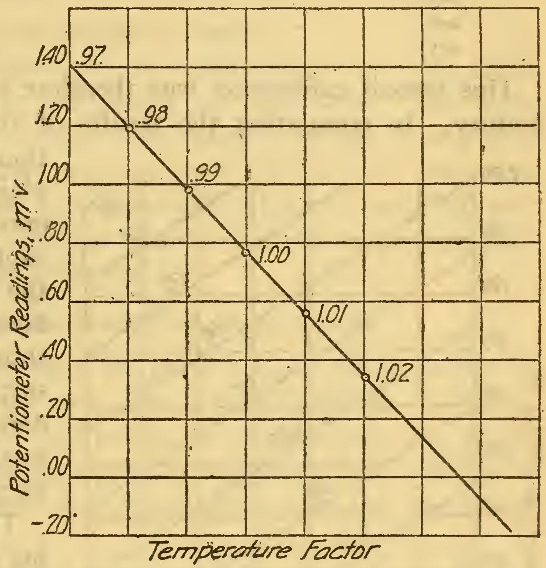

FIG. 5.—*Oxygen temperature factor curve*

CALIBRATION OF FLOW METERS.—Three independent calibrations were made of the orifices of each of the flow meters to determine the value of the constant K. In the first calibration the flow-meter readings were compared with the readings of a standardized dry gas meter. The pressure regulation was not as close as was desired, and the values of K fluctuated more widely than was considered satisfactory.

A second calibration was therefore made after the selected regulators and "rappers" were installed in the form used in the final blowpipe tests. As an additional check the dry gas meter readings were supplemented by the weight of the gas lost as determined by the balance. The regulation secured was excel-

lent and as a whole far better than was obtained in the blowpipe tests themselves. The results of this calibration were very consistent, as may be seen from the following table of values of *K* determined for one orifice under three widely different pressures and three widely different rates of flow:

Test No.	*K*
0-1	1.171
0-2	1.169
0-3	1.182
0-4	1.187
0-5	1.190
0-6	1.187
0-7	1.186

This second calibration was therefore at first considered satisfactory. In computing the results of the first blowpipe tests, there appeared an unexplained systematic difference between the gas consumption calculated from the balances and from the flow meters. Investigation showed the unexpected result that the value of *K*, as determined by the manometers used, was lowered by pressure fluctuations.

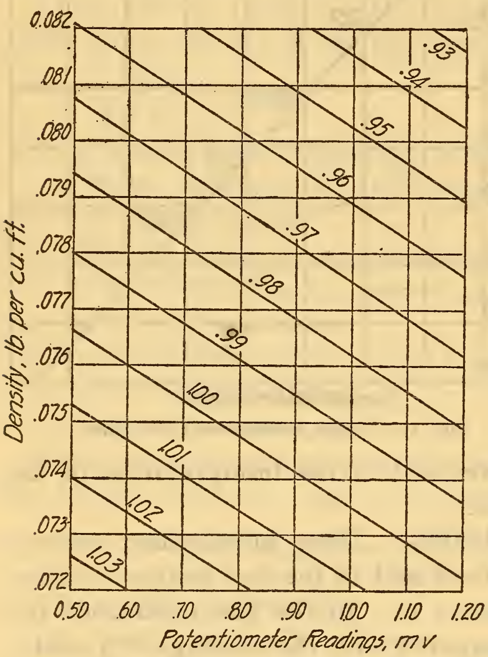

Fig. 6.—*Acetylene temperature factor curves*

The theoretically existing difference between the square root of the average value of *h* and the average of the square root of *h* is far too small to account for this difference. It must therefore be due to an actual higher average differential under fluctuating pressures, due to inertial and frictional effects in the manometers, or to a systematic tendency of the operator to overread a fluctuating manometer.

A full investigation of the cause of this systematic difference would be very desirable, but the time required would have been excessive in the present investigation.

A third calibration of the flow meters was therefore calculated from the balance and flow-meter readings in the preliminary

series of actual blowpipe tests. The pressure regulation in these tests was not so good as in the second calibration but better than in the first. The magnitude of this systematic effect of pressure fluctuation can be seen from the following table:

Calibration	Pressure regulation for orifice No. 5	*K*
2	Very good	1.189
3	Average	1.145
1	Poor	1.114

The effect is larger in the smaller orifices.

The flow-meter constants *K*, as determined from this third calibration, were used in computing the test data. The close check of the gas consumption calculated from the flow-meter readings with the balance readings in the individual tests (see for instance Figs. 22 and 23) shows that this was justified, and indicates that the same average closeness of pressure regulation was maintained throughout the tests.

(*c*) MANOMETER AND PRESSURE-GAGE EQUIPMENT

As indicated above, the gas leaving the flow meters passed to the blowpipe through the gas line *e* and flashback *f*, Fig. 2. The static pressure of the gas passed to the blowpipe was determined by means of pressure gages and manometers on the line *r*, Fig. 2, taken from the side of the flow-meter base just above the outlet to the gas line *e*.

On the oxygen side of the gage board there was incorporated in the line of static pressure *r*, Fig. 2 or 7, a Bourdon tube master gage *y*, a recording gage, and two compound manometers *z*, one of 0–44 $lbs./in.^2$ range, and the other 0–180 $lbs./in.^2$ This static line pressure also connected through the baffles *w*, Fig. 2, with the upper ends of the differential manometers. The other ends of the differential manometers, both vertical and inclined, were connected through reservoirs w', Fig. 2, to the static pressure lines at the inlet end of the flow meter just above the orifice opening.

On the acetylene side of the gage board the Bourdon tube gage was replaced by a simple mercury manometer z', which could be connected into the line as needed, and in place of the compound manometer *z* of the oxygen side there was installed a simple U-column mercury manometer.

The pressure gages used throughout the tests were a special series of master test gages that were made for this investigation.

The one at the oxygen side of the gage board was of 0–300 lbs./in.^{2} range, the one at the acetylene manifold of 0–500 lbs./in.^{2} range, and the one on the oxygen manifold of 0–3000 lbs./in.^{2} range. These gages were very carefully calibrated before being used for test purposes, and their calibration checked during the tests and at the completion of the tests. The Bourdon tube gages at the oxygen and acetylene manifold were used throughout the entire series of tests. On the other hand, the Bourdon tube gage on the oxygen side of the gage board *y*, Fig. 2, was seldom used, except in cases of heavy cutting where the pressure desired for delivery to the blowpipe exceeded the 180 lbs./in.^{2} range of the large compound manometer. The pressures actually delivered to the blowpipe, except as noted above, were always maintained constant by observation of the mercury manometers.

It was felt desirable to have an autographic record of the pressures at which the gas was delivered to the blowpipes for the various tests. Accordingly two special recording gages were installed in the static pressure line, the one used on the oxygen line having a range of 0–50 lbs./in.^{2}, and the one on the acetylene line a range of 0–15 lbs./in.^{2} A copy of one of these autographic records is shown in Fig. 31, which will give visual evidence of the uniformity of the pressure under which the blowpipes were operated during the tests.

As indicated above, the pressures during the greater part of the tests were maintained by observation of mercury manometers. Those on the oxygen side of the line are of particular interest in that they were special compound manometers devised for this investigation. In principle they consisted of a series of mercury U-tube manometers connected at their top by a water column in such a way that the movement of the first mercury column, in response to pressure from the line *r*, was transmitted to the second mercury column and simultaneously to the remaining mercury columns through the agency of the intermediate water columns. Fig. 8 shows the general construction of the larger of these manometers, which is a five U-tube manometer having a range of 0–180 lbs./in.^{2} The range of this manometer was increased by the addition of an upright riser filled with mercury, which displaced the initial zeros of the U-tube enough to increase the capacity of the manometer to an amount equal to the weight of the extra added mercury column. This instrument was used for maintaining oxygen pressures in excess of 50 lbs./in.^{2} On account of its extreme range the scale subdivisions indicating

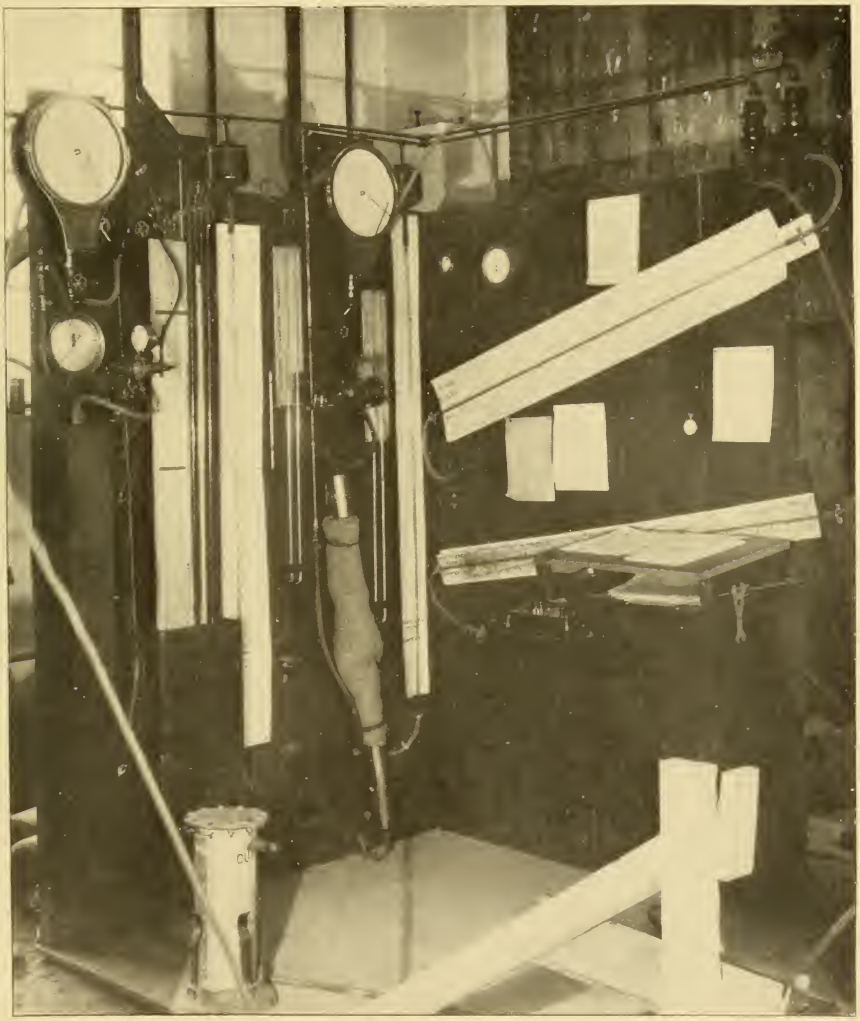

FIG. 7.—*Gage board with its equipment, showing gages and manometers*

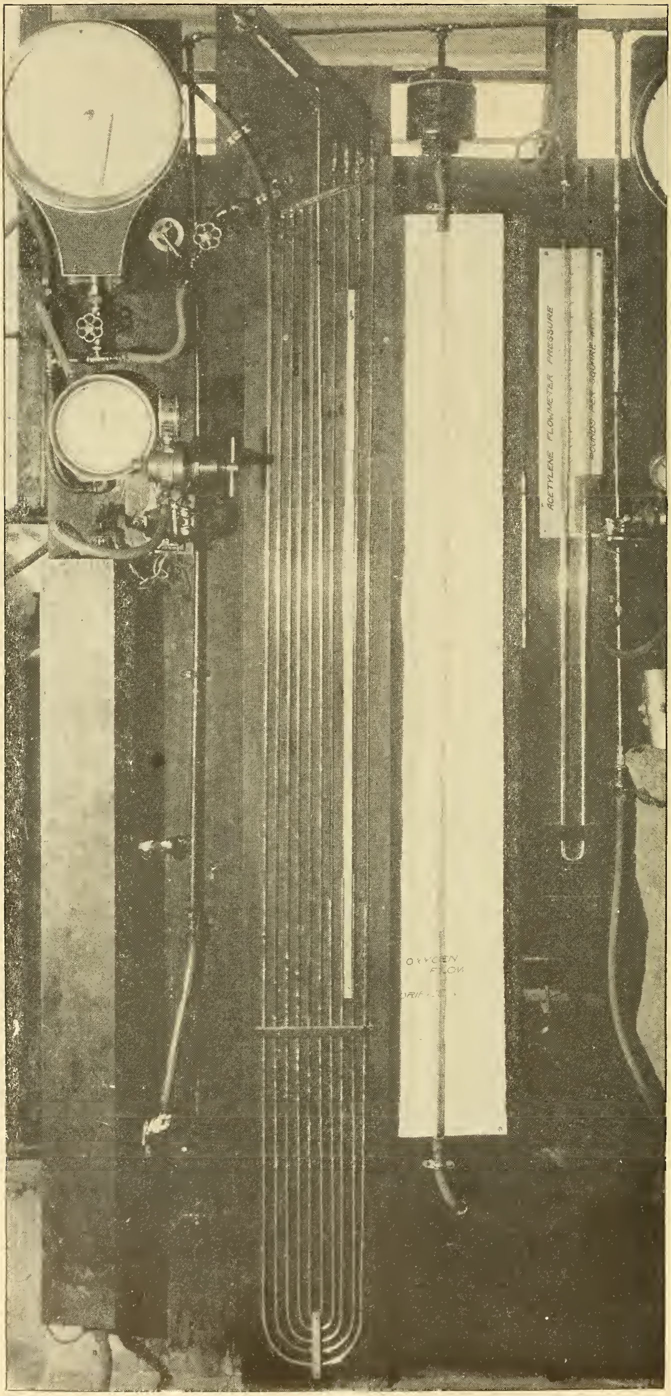

FIG. 8.—*Compound manometer used in investigation*

pressures lower than 50 lbs./in.^{2} were too small to permit of ready interpolation of pressures to the nearest 1/100 of a pound. There was therefore used in connection with this a smaller compound manometer of two U-tube construction with a range of 0–50 lbs./in.^{2} This latter was used for all welding tests and for the larger number of cutting tests.

These manometers gave extremely satisfactory service and proved a valuable addition to the gage-board equipment. The smaller compound manometer of 0–50 lbs./in.^{2} range proved to be extremely accurate and sensitive, and it was therefore selected as the pressure standard for the entire gage-board equipment. The remaining manometers and Bourdon tube gages, etc., were therefore frequently checked for accuracy against this manometer.

The greatest discrepancies in these manometers seemed to result from inaccuracies in the zero settings of the manometer scales. Errors due to this cause might possibly amount to 1½ per cent of the manometer reading for values below 5 lbs./in.^{2} For the higher values of the manometer readings, however, the error as a general rule ranged from 0.1 to 0.7 per cent.

Besides the Bourdon tube gages and the pressure manometers there was installed on the gage board as mentioned above a series of vertical and inclined differential manometers for measuring the flow-meter differentials. For the higher values of the flow-meter differential the vertical manometers were used, but the line was arranged so that for the lower values the inclined differential manometers could be cut in at will. The inclined manometer for measuring the differentials on the acetylene flow meter was mounted so that it could be set at either of two positions. (See Fig. 7.) These differential manometers were mounted with special calibration charts giving the flow-meter differential pressures and a series of curves enabling the determination by rough approximation of the rates of flow of the gas when the differential and the static pressure were known. The charts in question were based upon pressures above atmosphere standardized to 757 mm of mercury. The charts, however, are not fully described, because the readings obtained were only approximate since they did not contain corrections for temperature drop or changes in barometric pressure, nor did they take into account the question of the changing density of such gases as tanked acetylene. The general construction of these charts, however, is clearly indicated in Figs. 7 and 8.

In order to maintain the correct initial zeros for the flow-meter differential manometers, they had connected in their line at their base a small reservoir (w', Fig. 2). This reservoir was so mounted that by means of the lever and set screw the zero of the manometer could be readily adjusted.

It was found necessary to protect these instruments against accidental blowouts due to sudden back pressures caused by unforeseen gas explosions in the gas lines leading to the blowpipe. This was done by a baffle (w, Fig. 2) installed immediately over the top of each differential manometer, which interrupted any liquid accidentally blown out and, upon the release of pressure allowed the liquid to flow back into the manometer tube, permitting immediate continuance of the test without serious interference.

In order to complete the records in the test data, the gage board was also equipped with a standard calibrated thermometer, a psychrometer, a barometer, and a stop watch. (See Fig. 7.)

3. THE WELDING TABLE

All welding during the tests was performed upon the welding table illustrated in Fig. 9. This was a wooden frame table approximately 3 feet square, the top of which was composed of fire bricks. On top of the fire bricks was placed a heavy casting channeled for a width of about 6 inches throughout its length. This formed the base upon which all the plates for welding rested during the welding operation. The plates were aligned centrally along this base with the idea that the casting with its grooved surface would permit of better heat radiation along the line of the weld.

As indicated in Fig. 9, the line of the weld was placed directly in front of the welder and the welding was performed from the back toward the operator, thus giving him a full view of the work as it progressed. The welded plates were cut so that the welds were 1 foot in length. Where 2 feet of weld were made continuously, pairs of plates were set in front of each other with a slight space between the individual pairs and with proper allowance for expansion so that the process could be carried from one plate to the other without any interruption. The groove along the base plate facilitated the preheating of the second pair of plates, so that the start upon the second weld was made under conditions practically identical with those which existed when the first pair of plates was finished, a condition equivalent to welding one

FIG. 9.—*The welding table*

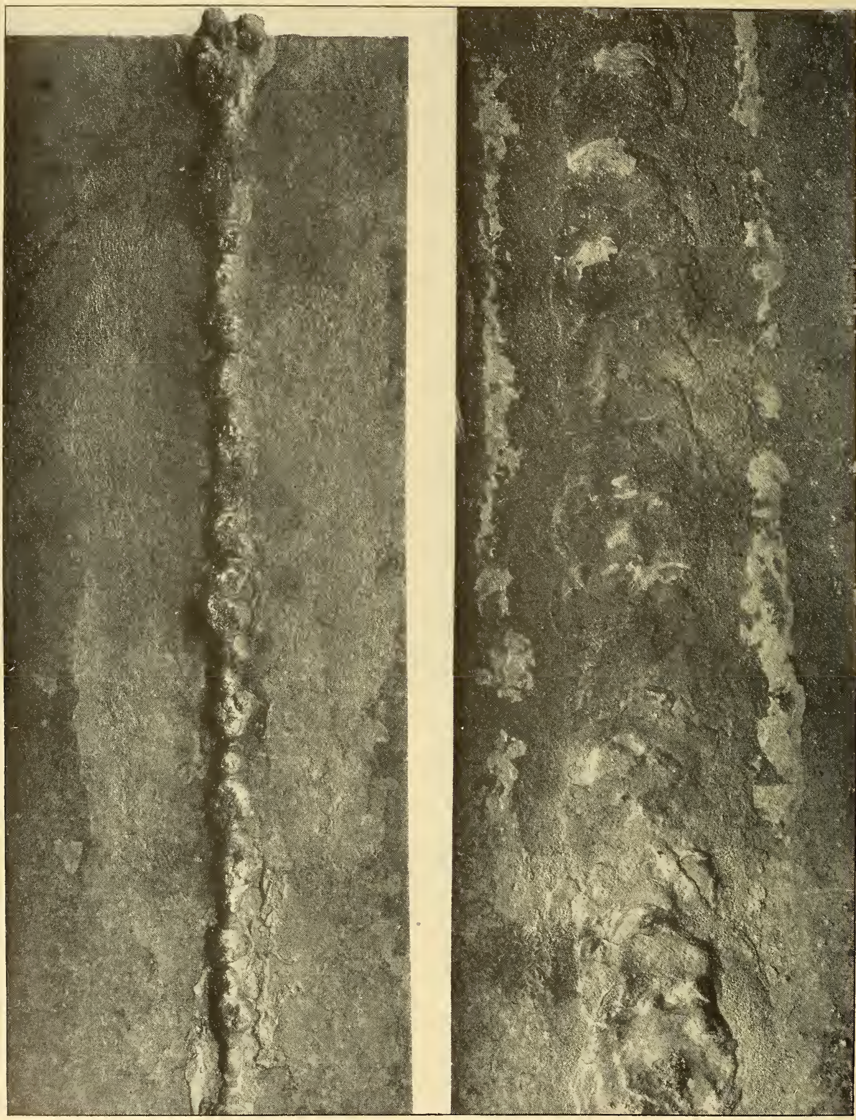

FIG. 10.—*The top and bottom view of an average weld*

2-foot length instead of two 1-foot lengths. Particular care was taken throughout the tests to level the plates before welding and to set them with a proper expansion allowance so that they would come together properly at the completion of the weld without overlapping. Fig. 10 shows the top and bottom view of an average weld. It will be noted that special attention was given to securing good penetration. The micrographs given later show further examples of the good penetration secured (Figs. 65 to 71).

4. THE CUTTING TABLE

In order to minimize as far as possible the personal equation entering into cutting tests all tests were made by a mechanically controlled cutting device installed upon the cutting table. (Fig. 11.) This was a wooden frame table approximately 4 by 12 feet in size with metal bound edges and a fire-brick top. At each end of the table and securely fastened to it were 6 by 6 inch sticks placed crosswise, along the top of which were fastened 1 by 2 inch bars of metal. These latter acted as runners to carry a channel placed with flanges down as illustrated in the figures. The channel held the track upon which the mechanically controlled cutting device operated. Longitudinal motion of the blowpipe could therefore be secured by causing the machine to move along the track and lateral shifts were made by sliding the channel along the runner bars screwed to the 6 by 6 inch end blocks. In order to facilitate quick lateral movement of the channel and insure, where such was desired, that pieces of definite width could be cut, the runner bars had a series of holes spaced conveniently at 2 inches on centers and a set of metal pins which fitted these holes. (See Fig. 1.) By inserting the pins in the proper holes the channel could be instantly shoved over a definite required distance.

This compound arrangement facilitated greatly the making of continuous cuts of 10 feet or upward. The cutting machine being fitted with a reverse motion gear could be operated in a forward direction for the full length of the table, reversed in direction of travel, and at the same time the channel slid over a definite distance and thus the blowpipe made to travel backward for the full length of the table for a cut on a new and adjacent line. (See Fig. 11.)

In order to furnish room for the disposition of the slag formed during the cutting operation, the metal to be cut was supported on

a system of teeth as shown in Fig. 11. These teeth proved extremely satisfactory and made a very convenient method of maintaining the metal in proper position for cutting. They could be shimmed to compensate for warped plates, and due to their tooth construction allowed the passage of slag without in any way blocking or interfering with the cutting operation during the test.

The mechanical guiding and controlling device proved extremely satisfactory and reliable, giving no trouble throughout the entire series of tests. The machine, however, was not arranged to allow of continuous variation of speed, which was necessary for an accurate determination of the maximum cutting speed. For this purpose a combination of series and shunt resistances was attached which enabled the speed to be varied continuously from about 1.5 to 25 feet per minute. For the purposes of the tests the blowpipe holder furnished with the machine was replaced by a special holder that would allow greater latitude in adjustment and would at the same time permit the machine to be adapted to hand-cutting blowpipes of all the various makes.

It was found in preliminary tests that the speed of the machine under all conditions remained practically constant for any particular adjustment. In order to make sure of this, however, the time was carefully noted for the various lengths of cut made during all tests. During the operation of the machine in the entire series of tests there was never noted a variation in speed that justified a rerunning of a test. (See Table 1 for a typical speed record.)

TABLE 1.—Time Speed Record for Cutting ½-Inch Metal, Torch No. 14

Length of cut in feet	Length of time to make cut	Time to cut each 5-foot increment
	Minutes	Minutes
0	0.0	0.0
5	2.73	2.73
10	5.42	2.69
15	8.28	[a] 2.86
20	11.01	2.73
25	13.78	[a] 2.77
30	16.52	2.74
35	19.28	[a] 2.76
40	22.03	2.75
45	24.88	[a] 2.85
50	27.58	2.70

[a] It was found during the tests that from 2 to 4 seconds were consumed in reversing direction of cut at end of each 10 feet of length.

FIG. 11.—*The cutting equipment*

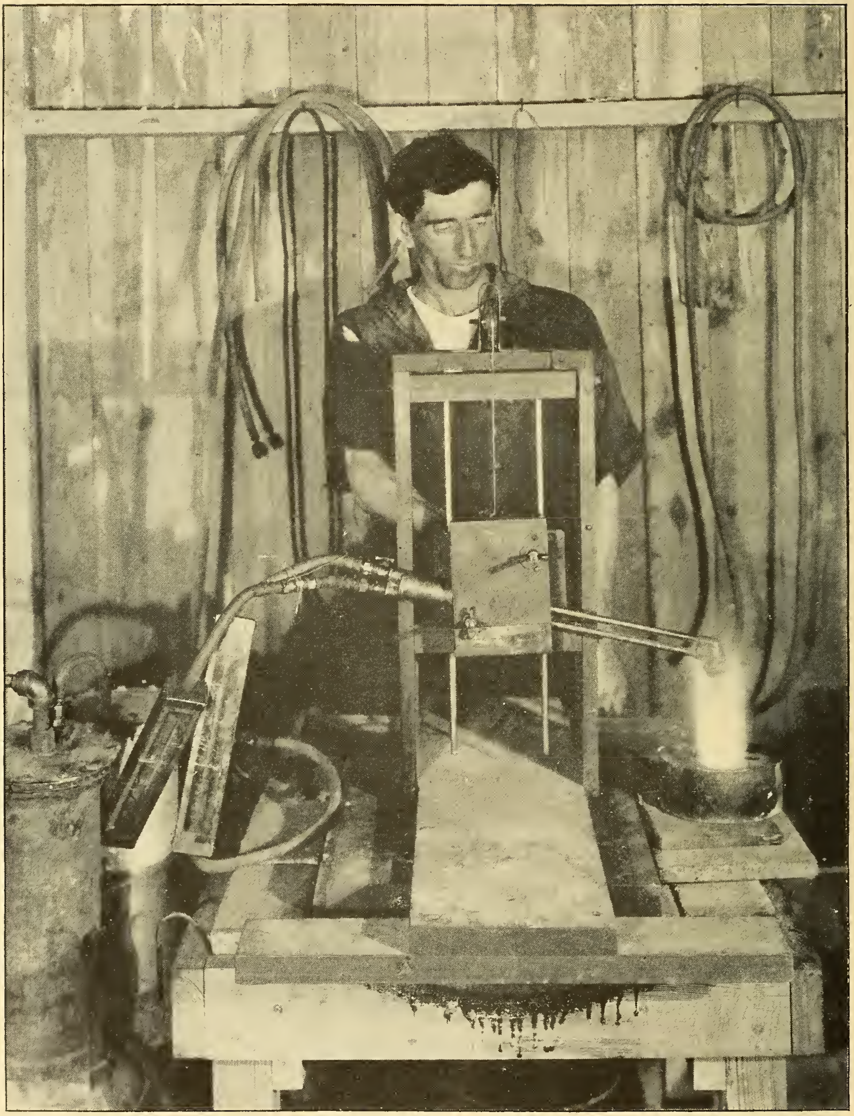

FIG. 12.—*The flash-back apparatus*

For convenience in handling, the material used during the cutting tests was cut into lengths of 3 or 5 feet. This necessitated the placing of two lengths of plates in order to secure the lengths of cuts desired in making the tests.

To minimize the delay in passing from the end of one plate to the beginning of another during the cutting operation, a method of preheating, as indicated in Fig. 1, was devised. As the blowpipe approached the end of the cut on one plate a welding blowpipe was ignited and played upon the edge of the second plate in line with the cut, thus preheating its edge so that the cutting blowpipe had a warm plate to attack in passing from the first to the second. It was found that by this method of preheating, bringing just a small spot at the edge of the second plate to a cherry red, the blowpipe could be operated continuously for the full length of the cut, cutting through the junction of billets 6 inches in thickness, without changing or slowing the speed of operation. Where the cuts were of such length as to require several traverses back and forth through the length of the table, such as the 50-foot cut for ½-inch plate, the same preheating with the welding blowpipe was carried out on the ends of the plate. (See Fig. 11.) This preheating therefore permitted the cutting operation to proceed as one continuous operation without any delay or interference from the fact that the test cuts were made on relatively short lengths of plate.

The entire cutting table equipment became practically a mechanically self-operating mechanism, inasmuch as after the maximum speed was obtained the only adjustment required of the operator was that necessary to keep the preheating flames of the cutting blowpipe at a proper distance from the face of the plate. This operation itself would have been unnecessary except for the fact that the cutting operation invariably caused considerable warping of the plate as the cutting proceeded, especially with the thinner plates.

It was the fixed procedure in making the cutting tests to adjust the blowpipe to neutral flame with the cutting oxygen valve at full opening and with the gases delivered at the required pressures. After such adjustment was satisfactorily made one or more preliminary trial cuts were made to determine the maximum speed at which the blowpipe would cut. The trial cuts for the major tests were always made upon a cold plate so that the effect of the heating of the plate in the cutting operation was

made negligible. By means of the mechanical gear shifts of the cutting machine and the resistances mentioned above, the maximum speed at which the blowpipe could operate was readily determined, and having determined this maximum speed the actual cutting operation required for the test was conducted. By the use of the mechanical driving mechanism the heating of the material during a test operation became ineffective inasmuch as the maximum speed was determined upon a cold plate, and from then on to the completion of the test the speed of operation of the cutting blowpipe was maintained constant by the mechanically operated mechanism.

5. THE FLASH-BACK AND SAFETY APPARATUS

(a) FLASH-BACK TANKS

The testing equipment also included in the gas lines two commercial flash-back tanks (*f*, Fig. 2, and Fig. 1). These tanks were essentially hydraulically controlled valves which were intended to prevent the propagation of an explosion in the blowpipe or gas line backward toward the gas supply. While it was realized that the installation of the water seal of these flash-back tanks might be considered detrimental, due to the absorption of moisture by the gas, it became evident that their installation was nevertheless a prime necessity as a means of protecting the rather expensive gage-board equipment. It was believed, further, that, inasmuch as the oxygen in use generally came from cylinders that contained more or less water, the passing of the gas through the hydraulic seal of the flash-back tanks would in reality tend to standardize the moisture content in the gas and therefore produce similar effects for all blowpipes.

These flash-back tanks proved extremely satisfactory for the purpose intended in that in several explosions they prevented the propagation of the flame beyond the flash tank. They generally ruptured by the blowing off of the head of the tank during the explosion. As furnished the heads were of rather thick sheet metal, fastened on with bolts. This construction proved to be somewhat dangerous to the operators making the tests, and the tanks were therefore modified in their construction by having a rubber packing and a thin sheet of metal fastened to the top with a heavy annulus. By this construction it was expected that if an explosion developed within the flash tank the thin metal sheet would rupture by tearing and thus minimize danger from flying parts.

(b) FLASH-BACK APPARATUS

The tests for freedom from flash back and safety in operation were conducted with the so-called flash-back apparatus. For this series of tests a pair of flash tanks was connected into the hose lines immediately back of the blowpipe. Between the flash tanks and the blowpipe proper two observation boxes were installed. These observation boxes consisted of a glass observation tube inserted in the gas lines and protected by a glass-covered box. The box was of wooden side and back construction with a vented back and a duplex glass face. The interior of the observation box was painted dead black to facilitate observation of the flame propagation. (See Fig. 12.) This equipment was used throughout the entire series of flash-back tests and for the severe flash-back test mentioned later. One further piece of equipment was a vertical sliding blowpipe holder constructed and operated as shown in the figure.

III. MATERIALS USED IN TESTS

1. WELDING ROD

The welding rod used throughout the entire series of tests was secured from the Naval Gun Factory, Washington, D. C. This rod was purchased in July, 1917, under Navy Department Specification 22–W–4. A number of chemical analyses were made to determine the composition, with the following results:

	Per cent
Carbon	0.024 to 0.03
Manganese	.05 to .08
Phosphorus	.01 to .015
Sulfur	.023 to .024
Silicon	.002 to .004
Chromium	Trace
Nickel	Not detected qualitatively
Vanadium	Do.

2. STEEL PLATES FOR WELDING AND CUTTING

The steel plates used for welding were ½ inch and ¾ inch in thickness. The material used for cutting was ½, 2, 6, and 10 inches in thickness. All the material used in both welding and cutting, except the 10-inch material, was furnished through the Engineer Corps, War Department, and was selected with special reference to uniform quality for any particular thickness. The ½-inch material was furnished in plates 3 by 5 feet in size and was used for both welding and cutting tests. For the welding tests

the plates were cut in sections 9 by 12 inches in size. The middle section of each plate was retained as a sample for determining the qualities of the plate. The remaining pieces were used for making welds. During the welding tests it was the practice to use plates that were adjacent to each other in the main or full plate before it was cut into weld specimens, so that as nearly as possible the material used for any particular test would be identical.

The ¾-inch material for welds was received in plates 12 inches wide by 6 feet in length. These plates were cut up into sections 9 inches in length, and for the full width of the plate, that is 12 inches. All specimens for welding tests were finished with a butt joint of the single V 90° included angle type.

For the cutting tests the 3 by 5 feet by ½ inch plates were cut into strips approximately 1½ to 2 inches in width, as indicated in the description of the cutting apparatus above. The 2-inch material for cutting was furnished in sections 2 inches by 6 inches by 20 feet. These were cut, for convenience in handling, into 5-foot lengths, and in test operations were cut lengthwise into sections of 2-inch width. The 6-inch material was shell billet steel furnished in 3-foot lengths and was cut lengthwise in test operations.

Analyses of these materials indicated that they contained approximately the following:

	Per cent
½-inch mild steel plate for welding and cutting tests:	
Carbon	0.14
Manganese	.32 to 0.36
Phosphorus	.012 to .013
Sulphur	.033 to .055
Silicon	.006 to .012
¾-inch plate for welding tests:	Per cent
Carbon	0.25 to 0.27
Manganese	.41 to .48
Phosphorus	.011 to .013
Sulphur	.041
Silicon	.004
2-inch mild steel for cutting tests:	Per cent
Carbon	0.19 to 0.20
Manganese	.42 to .44
Phosphorus	.025 to .027
Sulphur	.055
Silicon	.009 to .017
6-inch steel for cutting tests:	Per cent
Carbon	0.46 to 0.51
Manganese	.60
Phosphorus	.029 to .038
Sulphur	.064 to .067
Silicon	.13 to .14

For extra heavy cutting it was desired to determine what the various blowpipes could do on special material approximating armor plate in quality. For this purpose the Naval Gun Factory supplied a cast steel billet 10 by 36 by 50 inches in dimensions. This proved to be of the following chemical analysis:

	Per cent
Carbon	0.38
Manganese	1.21 to 1.27
Phosphorus	.038 to .043
Sulphur	.019 to .027
Silicon	.25 to .28
Copper	.96
Nickel	2.62 to 2.70
Chromium	less than 0.01

3. GASES

(*a*) OXYGEN

At the initiation of this investigation it was the intention of the Engineer Corps to supply the gas required for making the tests. The oxygen available at that time had been made by the liquid-air process. Later on the question came up as to the desirability of using gas of some other manufacture because the total amount of gas which would be required for the tests could not be secured from the Engineer's Depot at the Washington Barracks. After due consideration it was decided that it would be advisable to make the tests with oxygen made by the liquid-air process, as it is generally said that this gas as a rule did not run as pure as the electrolytic material and, further, that the impurity was an inert element in contradistinction to the impurity of the electrolytic gas. The decision was based upon the knowledge that the purity of the oxygen had considerable effect upon the cutting efficiency although its effect upon the welding tests is thought to be of minor importance. It was felt that if a blowpipe operated successfully on liquid-air oxygen of lower general average purity, it would operate at least equally as well on electrolytic oxygen of greater purity.

During the preliminary calibrations of the test equipment a number of tanks of oxygen were analyzed, and it was found that the percentage of purity ranged from 97.2 to 99.3, with the average analysis approaching very close to 98.3. Recognizing the effect the purity of the oxygen had upon the cutting efficiency of the blowpipe, it was necessary to establish and maintain as closely as possible a standard oxygen purity for all cutting tests. The average analysis of some 40 tanks of oxygen was therefore

assumed as the standard for this series of tests, this standard being 98.3 per cent pure oxygen.

In order to maintain the standard throughout the series of tests it was the practice to analyze each individual tank of oxygen and to determine its tank pressure. From these data the cylinders were selected so as to furnish as near as possible an average analysis agreeing with the desired standard, that is, 98.3 per cent purity.

After a group of tanks had been thus selected and banked and the manifold tested for leaks, a sample of the mixed gas from the manifold was analyzed for oxygen purity. This latter analysis is the one that is recorded on the log sheets of the various tests as the purity of the oxygen. Throughout the entire series of tests it was found possible to secure the standard required oxygen purity within ± 0.2 per cent.

The apparatus used for the analyses of oxygen was a modified Orsat gas analysis apparatus. The sample was measured over mercury and absorbed by an alkaline pyrogallol solution made up according to directions given by Prof. R. P. Anderson.[2]

The accuracy of analyses according to this method depends somewhat upon the size of the sample taken. When approximately 100 cm^3 of oxygen was taken it was found to be ± 0.1 per cent. This was the size of the sample used in analyzing the oxygen taken for analysis for the entire bank of cylinders. For the analysis of the individual cylinders a smaller sample, that is 25 cm^3, was taken from each cylinder. The accuracy of the method for the smaller sample is considered to be ± 0.2 per cent.

(*b*) ACETYLENE

In initiating these tests it was decided to use tanked acetylene in preference to generator acetylene, as it was known that the greater part of the War Department's field equipment would be operated from cylinders, and it was therefore felt that the comparison of the blowpipes should be made upon the basis of the type of gas with which they would be used in field service.

A commercial acetylene was suggested by the War Department and was therefore adopted as the standard and used throughout the entire investigation. The manufacturers of this gas claim a gas free from sulphur, phosphorus, lime, and water vapor. On account of the injurious effects of sulphur and phosphorus upon

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[2] R. P. Anderson, "Reagents for use in gas analysis," Journal of Industrial and Engineering Chemistry, 7, pp. 587–596, July, 1915.

the welding process, frequent tests were made to indicate the presence of these elements by the use of a silver nitrate solution. The results of this test throughout the entire investigation were always negative.

An attempt was also made to determine the acetone content of the gas as it was drawn off at various rates of flow from tanks under different pressures. As far as it could be determined there were no available data on this subject, but for the purpose of this test it was felt that an exact investigation to determine the acetone content of the tanked acetylene gas under the above-mentioned conditions would be far too extensive and costly.

To secure some information on the acetone content a portable Rayleigh type interferometer was used. This instrument is primarily useful for the analysis of binary mixtures or mixtures that can be made equivalent to binary mixtures by the removal of one or more gases. It was thought that this instrument, in offering a method of comparing the refractivity of two gases or gaseous mixtures, would offer at least a comparative determination of the acetone content of the acetylene gas as it was withdrawn from the cylinders.

The instrument is so designed that light passes through two tubes, one of which contains the gas mixture that is to be analyzed and the other contains the mixture without the constituent about which information is desired. To compensate for differences in the refractivity in the gas in the tubes and to measure such differences, a micrometer screw is arranged to move a thin plate of glass in the light passing through one of the tubes. After calibrating the scale on the screw for definite differences in refractivity it is very simple to make a calibration of the instrunent for the gas that is to be analyzed. In the work in connection with this investigation the refractivity of acetone vapor was taken as 1073 by 10^{-7}, the value determined by Prytz.

The standard gas for the use of this instrument—that is, the one in which no acetone was to be present—was obtained by connecting the instrument to an acetylene cylinder containing gas at approximately 250 pound pressure (in order to minimize as much as possible the probable acetone content), the gas thus obtained being passed through a solution of sodium bisulfide to remove such acetone as was present, from which it passed through a drying tube filled with calcium chloride. From this latter tube the pure acetylene gas entered one of the interferometer tubes. The gas to be analyzed for its acetone vapor content was also

drawn from the cylinders, but was passed only through a tube of calcium chloride to free it from water vapor, from which tube it passed to the second tube of the interferometer.

The information gathered by means of this apparatus and given below can not be considered reliable, as it will be affected by impurities in the acetylene or acetone, and, further, by the fact that the refractivity for acetone has not been definitely established, the figures of the different investigators being in disagreement by as much as 2 per cent.

One series of analyses was made upon gas taken from a single cylinder at 25 to 30 pounds pressure to find the effect of the rate of withdrawal of the gas upon the acetone content. It was later found that the flow-meter data indicating the rates of flow for this series of tests were incorrect, so that the exact rates can not be definitely established. For that reason the figures for this series of analyses are not given. The series, however, did as a whole show that the percentage of acetone vapor present increased with the rate of withdrawal of the gas.

A second series of analyses was made on gas taken from the same cylinder of acetylene but at different periods of its discharge with the idea of determining the effect the total pressure had upon the acetone content. In the figures given in the table below for this series of analyses the "theoretical per cent" represents the per cent of acetone vapor that should be in gas confined over liquid acetone under the same pressure at 20° C.

Pressure in pounds	Analyses	"Theoretical per cent"
	Per cent	
250	−1.5	1.3
190	+1.0	1.7
110	1.6	2.8
50	3.4	5.4

As is to be expected, there is a steady increase in the acetone content with decreasing cylinder pressure, but in no case is the percentage as high as that which might be theoretically expected. It is interesting to note in this connection that the first value given for this tank shows a negative acetone content. This negative value is without doubt due to the solution in the liquid acetone of some less refractive gas which more than counterbalanced the refractive effect of the small amount of acetone present. It is quite possible that this suggested phenomenon

is also responsible for the analysis value being consistently lower than that theoretically expected. In this connection there was also the possibility that the smaller amount of acetone vapor present is also due to the condensation effect mentioned under the discussion of density of acetylene gas.

While it is realized that the results mentioned above can not be considered reliable, it is believed they indicate that, with proper care and manipulation, this method of analysis might be used to secure accurate data concerning the purity of acetylene gas withdrawn from compressed-gas cylinders.

IV. SECONDARY STUDIES FOR SECURING DATA FOR INTERPRETING TESTS

1. CORRECTION OF FLOW-METER READINGS FOR TEMPERATURE CHANGES

The early calibration and experiments with the flow meters indicated that for the very low rates of flow the temperature effects would not be sufficient to warrant the use of a thermocouple on the acetylene line. When, however, the gage board was set in its permanent position and exposed to the heat given off during cutting, it was discovered that certain data would be considerably in error unless thermocouples were installed for both lines. All later and by far the greater portion of the tests were made with the thermocouples in both meters. In order that the few earlier tests which were made without the thermocouple in the acetylene meter might be made as fully as possible comparable to the later tests, a careful study was made to determine the average relationship between room temperature and that of the gas passing through the meters. It was learned that a straight-line relation would probably be accurate within at least 1 per cent, and the data secured from this study were therefore used in correcting the gage-board data secured without the use of the thermocouple in the acetylene meter. Later several check runs were made on the few blowpipes to which these corrections were applied, and the legitimacy of the method of the correction fully established.

2. CORRECTION OF BLOWPIPE DATA FOR ERRORS IN BOURDON TUBE GAGE

Once through accident the small manometer was blown out. In order to continue the tests without awaiting the installation of a new manometer, a Bourdon tube gage of from 0–50 lbs./ in.^{2}

range was installed to replace the injured manometer. This gage was put in without having been calibrated, and the tests on blowpipes of three different manufacturers were run with this gage before the compound manometer was repaired, calibrated, and reinstalled. A careful calibration of the Bourdon tube gage temporarily used showed that it was somewhat in error. Calibration corrections were therefore applied to the tests run with this gage. The welding pressures specified for one of these three blowpipes were entirely too high for the operation of the blowpipe, and the pressures used during the tests therefore bore no relation to the manufacturer's specified pressures. The data secured on that blowpipe were therefore not corrected for the errors in the Bourdon tube gage. Smaller calibration correction values applied to the pressures maintained for the other two makes of apparatus indicated that the pressures actually delivered to the blowpipes during the tests in which the Bourdon tube gage was used were practically identical with the specified pressures, the differences being very slight. It was felt, however, that in justice to the manufacturers the data secured should be as accurate as possible, and therefore an extra check weld of 2-foot length in ½-inch material was made for these blowpipes after the reinstallation of the repaired compound manometer.

3. GAS DENSITIES

(a) OXYGEN

Due to the use, in determining the volume consumed in any particular blowpipe test, of the method of substitution for tank weight loss, the question of gas density became of prime importance in the interpretation of test data. The flow-meter observations were also dependent upon a correct knowledge of the densities of the gas in use.

For the oxygen the value obtained by Morley of 1.4290 grams per liter was considered as the most satisfactory. This value was corrected for the average degree of purity of oxygen used throughout the tests, approximately 98.3 per cent, with nitrogen considered as the inert element present. Upon this basis the density of the oxygen was taken as 0.0890 lb./ft.^{3} This value was probably very slightly in error due to the fact that most of the tanks containing oxygen made by the liquid-air process have more or less water in them, which permitted the oxygen to draw over with it a certain amount of water vapor. However, the partial pressure of this water vapor is relatively small for high

tank pressures, and it is not until the tank is almost exhausted that an appreciable effect upon the density of the gas will be noticed. It was therefore not considered necessary to correct the value for the density assumed above for water vapor content, and it is believed that the error involved in this procedure was never greater than 0.5 per cent for all tank pressures above 300 lbs./in.^{2} The tank pressures were seldom lowered below this value during the test operations and in no case below 200 lbs./in.^{2} At the latter pressure the error in the density value due to the neglect of the effect of water vapor is about 0.7 per cent. It is probable then that the error in the interpretations of the test data on the basis of an assumed oxygen density of 0.0890 will in the great majority of the tests be below 0.5 per cent.

(*b*) ACETYLENE

The question of the density to be used for the tanked acetylene was far more complicated. An extended search indicated that practically no information was available concerning the density of acetylene drawn from dissolved acetylene cylinders. It is generally known that the density of the gas is affected by the temperature of the tank, the internal pressures, and the rate of withdrawal of the gas. Inasmuch as it had been decided to use tanked acetylene for this investigation, it was felt that some definite knowledge on this matter was necessary. Accordingly a series of tests was made to determine the probable densities of the gas at various tank pressures. The apparatus used in this determination consisted of the dry gas meter used for calibrating the flow meters with the acetylene balance system used during the tests. The gas was withdrawn from the bank at different rates of flow and was passed through the flow meter and the gas meter to the air. It was passed through the flow meter for a sufficient length of time to insure that the loss in weight of the tanks, as determined by the balance system, would have errors well within the generally accepted range of errors used throughout the investigation. During these runs a thermometer was kept at the outlet of the gas meter and observations of temperature and atmospheric pressure recorded in order that the dry meter volumes could be properly reduced to standard conditions.

Quite a number of runs were made to secure data for determining the density of acetylene. The gas as a rule was drawn from a bank of three tanks, and the principal study was made when it was withdrawn at the rate of approximately 30 cubic

feet per hour, which was considered to be about the average rate of flow actually used during the blowpipe tests. Additional test data were secured for gas withdrawn at the rate of 65 cubic feet per hour and at 11 cubic feet per hour. A short study was further made on the withdrawal of gas from a bank of two tanks at the rate of about 30 cubic feet per hour, which was equivalent to 45 cubic feet per hour for a three-tank bank.

In addition to the study made for this investigation, the Commercial Acetylene Co., through A. H. Ahldin, sent for comparison some additional information from density tests made by them with the Regnault apparatus. This latter work was based upon gas withdrawn from a single cylinder with discharges at the rates of 37.5, 15.7, and 9.3 cubic feet per hour. The values obtained from the latter study have been transformed to agree with the three-tank bank density determinations made for this investigation, giving density determinations for the rates of discharge of 112, 47, and 28 cubic feet per hour, respectively.

The entire data on density determinations thus secured are plotted in Fig. 13, and it will be noticed that the points representing the various rates of flow are designated also with a series of letters indicating the various gas banks from which the data were secured. This latter distinction seemed to be necessary, as the density studies indicated that for similar rates of flow different gas banks gave unlike densities.

A study of the plotted data in Fig. 13 indicates that the density is greatly affected by several conditions. First, it is apparent that it varies decidedly with the tank pressures, increasing rather rapidly as the tank pressure falls. Second, that the density varies with the rate of the withdrawal of the gas and seems to be highest for the lower discharges. Third, a marked difference in densities is especially noticeable at low tank pressures between different banks with the gas discharged at similar rates of flow.

The simplest assumption as to the cause for this variation in density is that the acetylene gas withdrawn from the tank carries with it a varying amount of acetone vapor, the amount of acetone present being that which might be expected in the same volume of acetylene in a system where acetone vapor and liquid acetone are in equilibrium. This assumption, however, does not pretend to account for the full amount of the acetone actually passing from the tank, as the varying densities would indicate that a greater proportion of acetone than that based upon the above assumption passes out with the acetylene. It is probable, there-

fore, that a certain amount of the acetone vapor is carried out mechanically as a fine spray in suspension in the acetylene gas.

It will be noticed in Fig. 13 that quite a number of the density determinations where the gas was withdrawn at 30 cubic feet per hour lie close to a definite curve from point *1C* to point *1B*. If these points are used for a simultaneous solution of acetylene

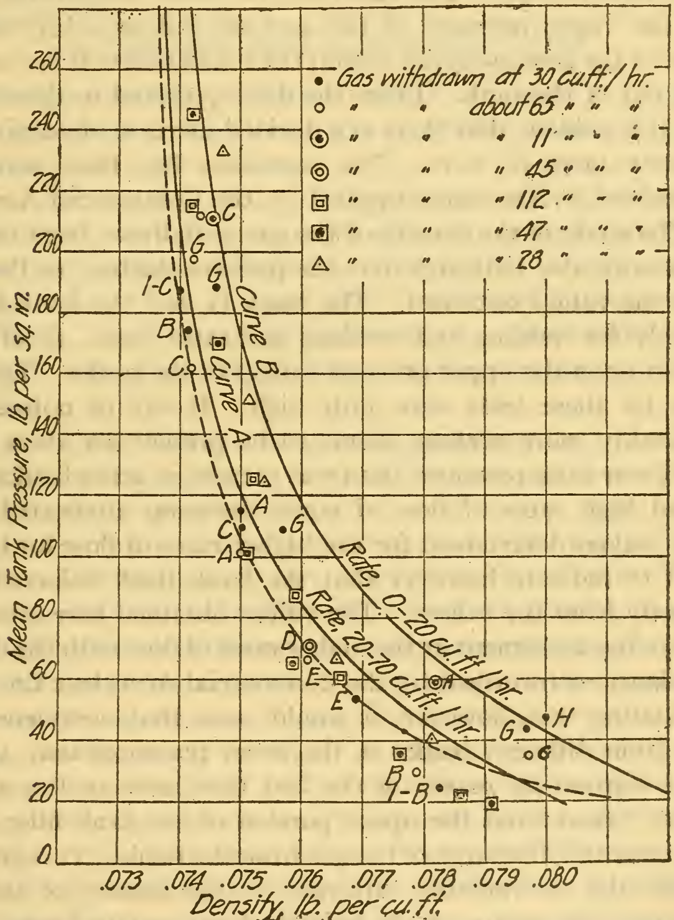

FIG. 13.—*Average density of acetylene*

density and the acetone vapor density, on the basis that both gases are in equilibrium, a value of 0.0725 lb./ft.^{3} is obtained for the acetylene density for the mean simultaneous solution of all of the points except the point *1B*. On the basis of this value and the average value obtained for the acetone density a theoretical density curve indicated by the dotted line in Fig. 13 can be drawn. An examination of the data plotted on the curve

indicates clearly that this assumption is fairly accurate for all tank pressures except the very low values.

As to the effect of the rate of flow upon the density of the acetylene, it seems evident that the lower acetone content for the higher rates of flow is to be most readily explained by the lower temperature of the gas withdrawn from the cylinders when the rate of flow is high. The effect of the lower temperature is to lower the vapor pressure of the acetone and probably collect a portion of the acetone spray within the tanks before it has entirely passed out of the tank. From the data gathered in this investigation it is evident that there is a decided increase of density with the lower rates of flow. This condition has been somewhat corroborated by the data supplied by the Commercial Acetylene Co. The study of the density of the gas withdrawn from tanks at low pressure also indicates that the previous history of the bank affects the values obtained. The bank G and the bank H were used only for welding and welding gas ratio tests, all of which were run upon the upper pressure ranges of the tanks. The rates of flow for these tests were quite high. It will be noticed that considerably more acetone seems to be present for these banks on the lower tank pressures than was present in other banks where low and high rates of flow of equal duration alternated. The density values determined for the higher rates of flow for bank G seemed to indicate however that the bank itself behaved quite differently from the others. The values obtained here seemed to to be in close agreement at the higher rates of flow with the density determinations furnished by the Commercial Acetylene Co. Notwithstanding this, however, it would seem that acetylene withdrawn from different banks at the lower pressures may vary in acetone content by reason of the fact that more or less acetone has been taken from the upper portion of the tank filler in the earlier or initial discharge of the gas from the bank. It is probable also that the unavoidable variations in the density of the filler may retard the escape of the acetone from certain tanks. This latter seems to be borne out by a statement of the Commercial Acetylene Co. to the effect that their experiments seem to indicate that different constructions of the porous fillings have a decided influence upon the density of the gas withdrawn.

In view of the greater discrepancies in the density values at the lower tank pressures it is quite evident that one continuous curve representing the probable average density of the acetylene

withdrawn from the banks could not be used in computing the volume flows. It was therefore decided that the best results would be obtained from the use of the two curves, *A* and *B*, shown on Fig. 13, curve *A* being used for the determination of the densities at the higher rates of flow and curve *B* being used for densities at the lower rates of flow. It is on the basis of the latter two curves that the volume computations in this report were made.

4. PRESSURE DROP IN GAS SUPPLY LINES

The oxygen gas line (*e*, Fig. 2) used for all welding, gas-ratio, and low-pressure cutting tests was a 28-foot length of ¼-inch flexible hose. For the extra heavy cuts (10 inches and above, test 9) a ⅜-inch hose of 26-foot length was substituted for the above. The acetylene gas supply line was a 30-foot length of ⅜-inch flexible hose. Throughout the entire investigation the flash-back tank (*f*, Fig. 2) was always connected in the acetylene supply line. A similar flash-back tank was used in the oxygen gas supply line only in the welding, welding gas ratio, and flash-back tests.

Due to the fact that the length of flexible hose used to transmit the gas from the regulator to the blowpipes was somewhat in excess of that in general use with such apparatus, and, further, inasmuch as the gas lines were supplied with the flash-back tanks, it was felt that the line drop through the hose and the tanks should be determined so that it would be possible to specify the actual pressure delivered at the blowpipe handle for the corresponding static pressure held at the gage board from line *r*, Fig. 2, as the manufacturer's specified regulator pressure. With the lines in the actual condition in which they were to be used and containing identical fittings and flash backs, observations were made by the use of mercury manometers to determine the line drops. The data secured from these observations were used in computing the results of the tests. Due to the fact that the differential manometers were used in several positions and that several different sized orifices were used in the flow meter, it was necessary to plot a number of curves to represent the particular conditions under which the line drop was desired.

In the interpretation of test data the static pressure held at line *r*, Fig. 2, as the manufacturer's specified regulator pressure, has been designated the "mean line pressure." This value has been corrected for the line drop furnished by the plotted data of the above-mentioned curves, and the corrected value is reported

as the "mean torch pressure," which is the pressure at which the gas was delivered to the blowpipe for the particular test in question.

5. LOSS OF PRESSURE THROUGH MANIFOLD

A study of the pressure drops through both the oxygen and acetylene manifolds was made to determine whether any possible difference existed between the pressure indicated on the gage and the mean pressures within the bank. The rates of flow of the acetylene gas were so low that there was apparently no noticeable loss of line drop on the acetylene bank. On the oxygen bank, however, it was found that when the rate of discharge was in the neighborhood of 3000 cubic feet per hour, there was a possible increase of 3 pounds in the pressure as determined from the gage observation made immediately after closing the line valve from the regulator and immediately before closing such line valve. This indicated that for all practical purposes the line drop within the manifold was negligible for all pressures and rates of flow used during the tests, and that it was only when the rate of flow exceeded 3000 cubic feet per hour, and the tanks were being discharged while under approximately full pressure, that any noticeable pressure drop was obtained. Even under these conditions the pressure drop within the tank valves and manifolds did not exceed approximately 3 pounds.

6. HAND VERSUS MACHINE CUTTING

All cutting done during the investigation on the tests of cutting blowpipes, with the exception of the cut for maximum thickness, was done as described above by means of a mechanically-controlled and guided holder. The decision to use this mechanical appliance was based upon three facts. First, it would tend to eliminate the uncertain personal equation of the operator; second, its performance when properly adjusted would be far more regular than could be expected of hand operation; and, third, it was felt that with such a method of operation the maximum cutting speed at which a blowpipe could be operated could be readily fixed and held for the entire test period.

It seemed desirable, however, that some information should be secured as to what might be expected by hand cutting, and with this in mind several cutting tests were run under like pressure conditions and on similar material with a blowpipe that had given rather satisfactory results as used in the cutting machine. The

data of the following table are given to show the comparative rates of cutting on 5 feet of ½-inch material.

TABLE 2.—Hand Versus Machine Cutting

Method	Pressure		Rate of flow		Rate of cutting	Comparison of hand with machine cutting		
						Ratio of rates of flow		Ratio of rates of cutting, hand-machine
	Oxygen	Acetylene	Oxygen	Acetylene		Oxygen	Acetylene	
	Lbs./in.²	Lbs./in.²	Ft.³/hr.	Ft.²/hr.	Ft./hr.	Per cent	Per cent	Per cent
Machine	20.0	3.0	39.5	8.04	61	104	96	73.8
Hand	20.0	3.0	41.1	7.73	45			

The hand cutting was done by the test operator, who has had a number of years experience with both oxyacetylene and oxy-hydrogen blowpipes, and the results show that with the best speed he was able to develop in hand cutting the machine cutting was some 25 per cent faster for the thickness of plate used during the test. This figure does not, of course, necessarily apply to all thicknesses of metal and to all conditions under which cutting operations are performed. It is probably true, however, that the difference between machine and hand cutting, up to what might be considered the commercial limit of oxyacetylene cutting, probably about 10 inches in thickness, will greatly increase with the increased thickness of metal. This statement, of course, refers to conditions where the machine operation can be used to advantage.

7. EFFECT OF THE PURITY OF OXYGEN ON EFFICIENCY IN CUTTING

Several of the blowpipes submitted for cutting tests failed to make cuts for the greater thicknesses of metal. One or two of these have generally been considered as better grade blowpipes, and it was therefore felt that if possible the reason for such failure should be determined. Discussion with the manufacturers of these blowpipes indicated that in at least one instance the blow-pipe was initially designed and proportioned for use with an electrolytic oxygen which was on an average of somewhat higher purity. It is known that the increased purity of the oxygen within certain limits has a decided influence on the efficiency of the cutting operation.[3] It seemed desirable, therefore, that

[3] Alexander E. Tucker, F. I. C., "The influence of impurities in oxygen when used for cutting iron and steel," J. of Soc. Chem. Ind., 30, No. 13, p. 779; July 15, 1911.

exact data based upon the apparatus developed for this investigation should be secured with the idea of establishing the probable differences which might be expected for oxygen of various degrees of purity. Difficulties were encountered, however, in securing a supply of tanked oxygen of the various degrees of purity desired. In view of the probable delay involved in completing the investigation, it was decided that no further work along this line would be undertaken.

8. DETERMINATION OF GAS VOLUMES CONSUMED BY LOSS OF PRESSURE INDICATED BY TANK PRESSURE GAGES

In general welding and cutting operations it is quite a common practice to determine approximately the amount of gas consumed on any particular piece of work by means of the loss of tank pressure indicated by gage readings. For oxygen the values thus obtained have proved fairly satisfactory, but acetylene gas volumes thus determined have never been found reliable. In general practice, therefore, the volume of acetylene used has always been taken as equivalent to the oxygen volume thus determined. This practice, of course, can be justified on theoretical grounds.

It was felt that a little study given to this matter might prove of interest, and an attempt was therefore made to determine a constant for both gases which could be considered the equivalent in cubic feet for a loss of 1 pound tank pressure.

The determination of a general useful constant for acetylene seemed to be impossible, as might be expected. As pointed out in the discussion on the density of acetylene, the conditions under which the gas is withdrawn greatly affect the amount of acetone withdrawn with it. Further, it was found that, at the lower pressures especially, there was a time interval effect which made volume determinations from pressure gage readings quite unreliable. This latter element seems to be due to the difficulty with which low pressure gas seeps through the porous filler. As an example of this it was observed on one occasion that the acetylene bank pressure gage at the completion of one day's tests read 70 lbs./in.^{2} with a room temperature of 85° F. The following morning with a room temperature of 84° F the same test gage read 85 lbs./in.^{2}, the gain apparently being due to the fact that, at the earlier reading the gas pressures in the bank had not reached a state of equilibrium. In fact the test gage will nearly always show, a few minutes after the completion of a test, a reading

of from 1 to 3 pounds higher than that taken immediately at the completion of the test.

With the above in mind it was felt that the best approximate constant could be obtained from actual blowpipe test data using the volume by balance as the true volume. From this latter method a constant of 2.2 ft.^{3}/lb./in.^{2} of bank pressure (three tanks, 225 cubic feet capacity) was derived and used in the reduction of test data for determining the volume of gas used, as indicated by gage pressure observations.

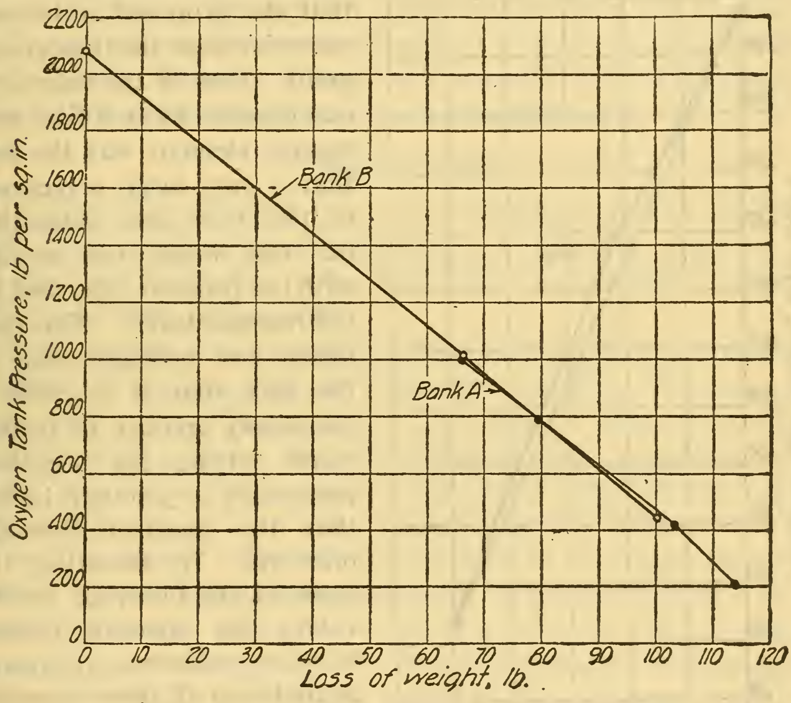

FIG. 14.—*Loss of oxygen corresponding to tank pressure*

In order to determine the oxygen equivalent in cubic feet for a loss of 1 lb./in.^{2} bank pressure, a study was made of two representative oxygen banks. The total loss of weight of the banks is shown plotted against gage pressure in Figs. 14 and 15. Two oxygen banks were used by reason of the fact that it was known that occasionally water may take up considerable space in the bottoms of the oxygen tanks. The two banks were therefore studied in order to determine whether any great differences existed between the banks themselves. A slight difference in the capacity of the banks seemed to be perceptible. For the purpose of approximate volume determinations the selection of a mean value for the

number of cubic feet per pound per square-inch gage pressure seemed warranted. This value was taken as 0.68 ft.^{3}/lb./in.^{2} of bank pressure or gage pressure for a 7-tank oxygen bank with tanks of 200 cubic feet capacity.

V. DESCRIPTION OF THE TESTS

The investigation was started with the idea of submitting each manufacturer's equipment to a much more extensive series of tests. It was found, however, that the proposed series was excessive from the time standpoint. One of the most serious drawbacks as a time consuming element was the fact that a very large percentage of the blowpipes submitted for test would not operate with the pressures specified by the manufacturers. This condition was probably due to the fact that it is quite a customary practice to recommend setting the regulator pressures 3 to 5 pounds higher than the specified blowpipe pressures. By throttling the gases at the blowpipe handle valves the operator insures having sufficient pressure available at all times to maintain the required velocity of exit of the gases at the tip end. He is therefore enabled to compensate for pressure fluctuations due to irregular action of the regulator, thus tending to minimize the development of flash backs. The specifications for the tests distinctly stated that at least one of the blowpipe handle valves must be maintained at full opening during a test. It was only by such a procedure that the gas consumption of a blowpipe could be definitely ascertained. For a great many of the blowpipes the pressures were too high to

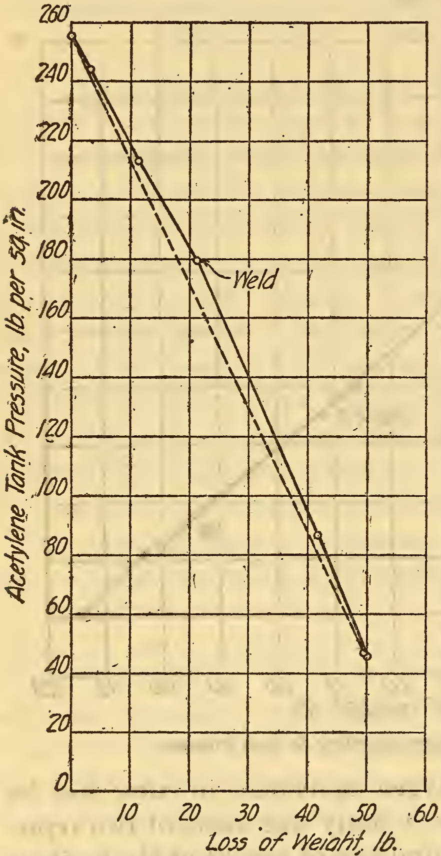

FIG. 15.—*Loss of acetylene corresponding to gage pressure*

enable the maintenance of a stable flame with one of the handle valves at full opening.

Another quite serious source of trouble from the standpoint of time consumption was that due to leakage, necessitating the dismantling and repacking of the valves.

In order, therefore, that the entire investigation might not require an undue length of time it was decided that attention should be devoted only to the so-called primary tests, consisting of the welding, cutting, gas ratio, and flash-back tests. Such proposed tests as the variation of pressure within the blowpipe head, etc., were therefore abandoned. On the basis of the above the following schedule of tests was adopted and all blowpipes tested during this investigation were submitted to it.

1. WELDING TESTS

All blowpipes reported upon were submitted to five welding tests, designated respectively as tests 1–a, 1–b, 1–c, 1–d, and 2. All the tests numbered 1 were made with ½-inch plate. Test 2 was a weld with ¾-inch plate.

Tests 1–a and 1–b were made with the tip sizes and pressures specified by the manufacturer if this were possible. For both of these tests a 2-foot length of weld was made. These tests were identical in all respects, with the exception that an attempt was made to evaluate the personal equation by using different operators. For tests 1–c and 1–d a 12-inch length of weld was made. Both of these welds were made by the operator who made the weld of test 1–a, the idea being to maintain as nearly constant a personal equation for this series of tests as possible. Test 1–c was run with the same size tip as 1–a, but with pressures (both oxygen and acetylene) 50 per cent in excess of the pressures used for test 1–a. Test 1–d was carried out similarly to 1–c except that the pressures were 25 per cent below those used in test 1–a.

As mentioned above, the pressures specified by the manufacturer very often gave an exit velocity to the gas too high to permit of maintaining a stable flame at the blowpipe tip. In such cases the manufacturer's representative was requested to furnish a modified pressure that would enable the maintenance of a stable welding flame. Very often the modified pressure thus determined upon would not permit of the application of test 1–c; that is, a test with a 50 per cent increase in pressure in both gas lines. It was customary, therefore, in such cases to modify the test procedure and incorporate as a test in place of test 1–c, test

1–e, which was run under identical conditions with the above test, with the exception that the pressure on both gas lines was reduced to 50 per cent of the pressure used to make test 1–a.

Tests 1–c, 1–d, and 1–e were incorporated to show the effects of increased or decreased pressures on the operation and economy of the blowpipe. Such excess or decreased pressures are found to be quite common in many welding operations, due to carelessness on the part of the operator in setting regulator pressures or to imperfect regulator action. It was felt that a properly designed blowpipe should be capable of adjustment over a considerable range for any specified tip size. It was hoped in the investigation to secure data that would either verify this assumption or prove that it was absolutely essential to maintain exact pressures for satisfactory blowpipe operation.

Test 2 was a 12-inch length of weld of ¾-inch mild steel plate. This weld was made in all cases by the operator, who made the weld of test 1–b. This test was selected as indicating the probable results to be obtained with a blowpipe in heavy welding, and with test 1 it was felt that it would give a fair idea of the adaptability of the blowpipe for welding purposes. The tips for welding ½ and ¾ inch plate were selected as being the tips used respectively for the average size weld and for the maximum size weld and therefore the best general average for determining the blowpipe's efficiency and safety.

2. CUTTING TESTS

The cutting blowpipes reported upon have been submitted to eight cutting tests, four of which may be considered primary. In each of the cutting tests a length of cut was made sufficient to determine accurately the gas consumption of the blowpipe. Test 6–a consisted of cutting continuously 50 linear feet of ½-inch mild steel, test 7 was a continuous cut of 10 feet of 2-inch mild steel, test 8 was a continuous cut of 6 feet of 6-inch medium steel, test 9 was a cut by hand for maximum thickness.

As indicated above in the description of the cutting test equipment, each test cut was preceded by a preliminary trial cut to determine the maximum speed at which the blowpipe would cut with the tip size and pressures specified by the manufacturer for the particular thickness of metal. It was found during these trial cuts that the same condition existed relative to the cutting blowpipes that was found to exist with the welding blowpipes, that is, that a great many of the pressures specified by the manu-

facturers for cutting particular thicknesses of metal were not suitable for the work intended. One of the main troubles seemed to be that the majority of the blowpipes were operated with preheating flames of too high intensity.

Throughout the entire series of cutting tests all blowpipes were operated similarly, that is, at least one of the gas control valves for the preheating flames was at full opening, the preheating flames were adjusted to neutral with the oxygen cutting valve at full opening, and all cutting operations were started with this latter open. Some criticism of this procedure developed from time to time, but throughout the entire series of tests it was found that at no time were any detrimental results produced, and that even on cuts as heavy as 16 inches no trouble was found in starting with the oxygen cutting valve open. This method was adopted to insure the maximum capacity of the blowpipe throughout the entire test period, and, further, to enable the maintenance of accurate pressures throughout the test and insure accurate data as to the maximum gas consumption during the cutting operation.

Test 9, cutting for maximum thickness, was originally conducted with the idea of submitting the blowpipe to a test for the maximum thickness specified by the manufacturer as permissible for his blowpipe. It was found during the course of the investigation that the great majority of the blowpipes would not successfully cut the so-called maximum thickness specified by the manufacturers. Experience during the investigation seemed to indicate that the probable maximum commercial limit for economic heavy cutting operations when the cut is made in one direction only with an ordinary stock blowpipe, lay in the neighborhood of 10 inches. It was therefore decided that all blowpipes should be submitted to the same maximum or heavy cut. A cut in material 10 inches in thickness, of 12 to 18 inches in length was therefore made as a supplementary heavy cut test for each blowpipe.

The tests for maximum thickness of cut were made by hand. On account of the possibility of damage to the gage-board equipment caused by heavy slag showers from pockets, etc., produced during cutting, this test was conducted out of doors. The original tests for maximum thickness were therefore made on different days with the temperature of the metal varying from 35 to 68° F. After the decision had been made to submit all blowpipes to cutting tests of identical thickness, it was decided to minimize the effects of varying temperature as much as possible on the heavy cut by making all cuts during the course of one or two days. By

this procedure only a slight temperature change occurred. Particular care was also exercised to insure that a blowpipe was not submitted to test on pieces of the steel ingot used for this work that were still warm from a test of another blowpipe. The test for heavy cutting—that is the special 10-inch cut just described—is listed as test 9 in the data that follow.

Besides the primary tests it was thought desirable also to determine the efficiency of the blowpipe as it was affected by variations in the oxygen pressure supplied. For this purpose a series of supplementary tests listed as tests 6–b, 6–c, 6–d, and 6–e were conducted. These were made on ½-inch mild steel plate and a cut of 10 linear feet made for each test. In this entire series of tests the tip sizes and the conditions of cutting were identical with test 6–a listed above, with the exception that the oxygen pressures alone were modified. These were increased 50 and 25 per cent and decreased 25 and 50 per cent respectively for tests 6–b, 6–c, 6–d, and 6–e. No change was made in the acetylene pressure. A slight aspirating effect for the increased oxygen pressure was expected and was shown in the volume of the acetylene used.

3. GAS-RATIO TESTS

One of the prime essentials of a good welding blowpipe is its so-called gas ratio—that is, the ratio of the volume of oxygen to the volume of acetylene consumed. Theoretically a properly adjusted blowpipe requires equal volumes of both gases, giving a one-to-one ratio. In order to establish the ratios of the blowpipes under test, each one reported upon was submitted to a series of gas-ratio tests, numbered 5–a–1 and 5–b.

For these tests the blowpipe was allowed to burn freely in air with the same tip sizes and pressures as were used in the welding tests mentioned above. The blowpipe was supported upon a bracket stand with the tip in horizontal position. All gas-ratio tests were made upon the tips used for welding, and no attempt was made to clean them before making the tests other than to blow them out with a rather high oxygen pressure. These tests might be expected to indicate the gas consumption of the blowpipe with the flame burning undisturbed from accidental obstructions, such as slag adhesions to the ends of the tips, etc., which occur in actual welding practice. The discussion of the welding blowpipe furnishes additional interesting information concerning the gas-ratio tests.

4. FLASH-BACK TESTS

In order to determine the probable safety of operation of a welding blowpipe and, further, to secure information concerning the permanency of construction of the tip and blowpipe head, the blowpipes reported upon were submitted to two types of flash-back tests.

One series of tests, designated 3–a and 3–b, flash-back tests on the tips used for welding ½-inch metal and ¾-inch metal, respectively, consisted of the standard series of tests used by the Underwriters' Laboratories for determining the freedom from flash back and the safety of the welding blowpipe. Each of these tests consisted of four distinct operations. The first three of these operations were carried out as follows: After being properly adjusted to neutral flame the blowpipe was tested for flash back by drawing the tip at varying angles across the surface of and finally pressing the tip end firmly against certain materials. For this test a cold steel plate, a fire brick, and a piece of wood were used. Finally, the tip was used to make a pool of molten metal in a cast-iron block, flux being used to assist in maintaining the fluid condition of the metal and the tip suddenly plunged into the pool of metal.

Another series of tests intended to determine the permanency of construction and designated as the "severe flash-back test," test 4, was carried out by supporting the blowpipe on a vertical sliding carriage in such a manner that at the proper instant the ignited and carefully adjusted blowpipe could be lowered so that the end of the tip was directly over the center of a hole 2 inches in diameter and 2 inches deep, drilled in a heavy cast-iron block (Fig. 12).

Experiments in the development of the severe flash-back test indicated that this procedure, by causing a reflection of the flame up about the head of the welding blowpipe and concentrating the entire flame about the tip and blowpipe head, not only caused the development and propagation of a true flash back with all blowpipes but further caused the tip to become red hot and tended to melt the brazed joint at the juncture of the gas tubes and the blowpipe head. While this test might be considered rather severe, inasmuch as it will not occur in general, ordinary practice, the condition is nevertheless likely to occur to rather a large extent in welding in corners, etc. Further, by being easily duplicated as to conditions it permitted the obtaining of definite information as to the effects of excess heat upon the blowpipe tip and head.

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In all the tests for flash back the flash-back observation boxes mentioned above in the description of the testing apparatus were used and careful notes taken to record the behavior of the conditions developed during the tests. In the case of the severe flash-back test, test 4, particular attention was also paid to the effect of excess heat upon the blowpipe heads and as to whether the gases could be shut off and the blowpipe relighted after the flash back had occurred without the necessity of cooling the blowpipe with water.

In all the flash-back tests the blowpipe was operated under the identical conditions at which it was supposed to be used during the welding operations, and after the initial adjustment of the flame no further adjustments were permitted. Following also the procedure in the welding tests, at least one of the blowpipe handle valves controlling the gas had to be at full opening.

In first carrying out the severe flash-back tests the investigation indicated from time to time minor points for consideration which had not been thought of in previous tests. It was therefore decided to rerun the entire series of severe flash-back tests so that each blowpipe would be submitted to identical tests and observed in like manner. The results of the latter tests only are recorded in this report.

5. LOG SHEET RECORDS OF TESTS

It has not been thought advisable, in the light of the discussions following, to incorporate as part of the report the complete set of test log sheets, especially as there are over 1900 of them. In order that an idea may be had of the amount and extent of the data taken for each test, a few typical log sheets representing the data taken for one manufacturer's apparatus are reproduced in Figs. 16 to 31.

VI. DISCUSSION OF TEST RESULTS

1. GENERAL BASIS OF CONSIDERATION

For convenience in analysis the results of these tests have been summarized in a series of tables (Tables 3 to 7) and plotted graphs, Figs. 32 to 41 and 51 to 60. In the plotted summaries are shown the results of tests on blowpipes from 14 different manufacturers, each represented by a designating number. The group submitted to test comprises most of the better-known and more widely advertised makes of apparatus on the American market and includes besides those voluntarily submitted the three makes of apparatus that were withdrawn by their manufacturers because of disagreement over methods of test procedure. Samples of these latter three were purchased for test purposes.

Date 3-17-20
Computed by A.T.D.
Checked by M.L.C.

Sheet No. 1

Summary of
Welding Test No. 1-a

Style of Torch L No. 7860
Manufactured by

Thickness of Plate 1/2 in. Length of Weld 24 in.
Time to Make Weld 44 min. 3 sec.
Linear Feet Welded per Hour 2.72
Characteristics of Welded Material
1. Tensile Strength 32000 Lb. per Sq. In.
2. Ductility. Bent to Included Angle of 43 Degrees
3. Structure of Weld Slightly crystalline, adhesion

Pressure, Gas Consumption and Rate of Flow

	Oxygen	Acetylene
Mean Line Pressure - Lb. per Sq. In.	6.25	8.00
Mean Torch Pressure - Lb. per Sq. In.	5.32	7.35
Weight of Gas Used - Pounds	3.812	2.620
Volume in Cu. Ft. ~~per Hour~~ Determined From		
1 - Weight of Gas Used	42.85	35.31
2 - Flow Meter Data	42.8	36.3
3 - Test Gage Readings	37	37
Mean Rate of Flow by Flow Meter	(58.4)[a]	(48.1)[a]
Cubic Feet per Hour	58.2	49.5

Volume Ratio Oxygen to Acetylene
1 - By Weight Density Method 1.21
2 - By Flow Meter 1.18

[a] By Balance

FIG. 16.—*Log sheet No. 1, summary—welding*

Date 3-17-20
computed by A.H.S.
checked by L.R.S.

Sheet No. 2

Summary
of
Test No. 19

Record of Torch Consumption

Time Minutes	Rate of Flow Cu. Ft. per Hour Oxygen	Acetylene	Volume Ratio Oxy.:Acet.	Time Minutes	Rate of Flow Cu. Ft. per Hour Oxygen	Acetylene	Volume Ratio Oxy.:Acet.
1	60.2	50.8	1.18				
3	58.9	50.0					
6	58.7	49.9					
9	58.6	49.9					
12	58.5	49.7					
15	58.2	49.4					
18	58.0	49.6					
21	58.0	49.6	1.17				
24	58.0	49.9					
27	57.8	49.3					
30	57.8	48.9					
33	57.6	49.0					
36	57.6	48.8					
39	57.6	48.7					
42	57.4	48.7	1.18				

Remarks:

FIG. 17.—*Log sheet No. 2, summary—welding*

Date 3-17-20
Recorder Waite
Observer

Sheet No. 3

Weighing Table Log Sheet
for
Welding Test No. 1-a

Style of Torch L No. 7860

Manufactured by

Serial No. of Weld 6-a-1.6-a-2 Operator E. A. J.

Thickness of plate 1/2 in. Length of Weld 2 ft. Tip No. 9

Manufacturer's specified pressures:

Oxygen 6.5 lb. per sq. in. Acetylene 8 lb. per sq. in.

Pressure at which gas was delivered to torch line:

Oxygen 6.25 lb. per sq. in. Acetylene 8 lb. per sq. in.

Number of Gas Tanks in bank: Oxygen 7 Acetylene 3

Average analysis of gas in bank: Oxygen 98.3 Acetylene (97.8)

	Weight of Plates	Weight of Welding Rod
Before Welding	58.5 lb.	2005 grams
After Welding	60.5 lb.	980 grams

Gases used as determined by loss in weight of Tanks:

Oxygen 1730.2 grams Acetylene 1189.5 grams

Time to make weld 44 min. 3 sec.

Remarks:

Fig. 18.—*Log sheet No. 3, weighing table summary—welding*

Date 3-17-20
Recorder Waite
Observer

Sheet No. 4

Log Sheet
Test No. 1-a

Style and No. of Torch L 7860
Mfg. by

Operator E.A.I.

		Oxygen Scale Reading	Oxygen Zero	Acetylene Scale Reading	Acetylene Zero
Initial		4.55		24.42	
		12.63	8.55	32.52	28.52
		4.40	8.31	24.63	28.50
		11.83	8.05	32.23	28.46
		4.16		24.78	
True Zero			7.79		28.54
Final		11.23		23.86	
		3.10	7.08	31.08	27.49
		10.91	7.10	23.96	27.48
		3.48	7.13	30.92	27.52
		10.65		24.28	
			7.10		27.49
Displ. of Zero			.69		1.05
Sensitivity			1.82		1.42
Value of Displ.			12.5		14.9
Loss per minute			.19		.10
Time			44 min. 3 sec.		
Value of Loss			-8.3		-4.4
Total Correction			4.2		10.5

	Oxygen	Acetylene
Replacement Weight	1726.0	1179.0
Correction	4.2	10.5
True Weight	1730.2	1189.5

FIG. 19.—*Log sheet No. 4, weighing table—welding*

Date 3-17-20
Recorder Deming
Observer Deming-Sweetman.

Sheet No. 5

Gage Board
Log Sheet
for
Welding Test No. 1-a

Torch manufactured by

Serial No. of Weld 6-a-1, 6-a-2 Operator E.A.J.

Thickness of Plate ½ in. Length of Weld 2 ft. Tip No. 9

Manufacturer's specified pressures:

Oxygen 6.5 lb. per sq. in. Acetylene 8 lb. per sq. in.

Pressure at which gas was delivered to torchline:

Oxygen 6.25 lb. per sq. in. Acetylene 8 lb. per sq. in.

Tank Pressures:	Oxygen	Acetylene
At start	845	193
At end	790	176

	Temperature (Room)	Barometer	Humidity
At start	70.9	759	.49
At end	72.0	753	.50

Position of Manometers: High — Low — Vertical 0 A

Orifice No. Oxygen V Acetylene IV

Temperature reading of orifice: Oxygen Acetylene

	Oxygen	Acetylene
At start	.78 m.v.	.78 m.v.
At end	.78 m.v.	.78 m.v.

Time required to make weld 44 min. 3 sec.

Remarks:

FIG. 20.—*Log sheet No. 5, gage board summary—welding*

Date 3-17-20 Sheet No. 6
Recorder Deming
Observer Deming-Sweetman

Pressure and Flow Meter Log Sheet
for
Welding Test No. 1-a

Torch manufactured by ____________

Serial No. of Weld 6-a-1, 6-a-2 Operator E.A.I. Tip No. 9

Pressure at which gas was delivered to torch line:

Oxygen 6.25 lb per sq in Acetylene 8 lb. per sq. in.

Time	Poten.	Pres at Reg Oxygen	Pres at Reg Acety	Flow meter differentials Oxygen	Flow meter differentials Acety.	Time	Poten.	Pres at Reg. Oxygen	Pres at Reg. Acety.	Flow Meter differentials Oxygen	Flow Meter differentials Acety.
1	.78	6.30	8.06	132.0	75.9						
3		6.25	7.99	126.4	73.6						
6		6.25	8.00	125.6	73.2						
9		6.25	8.00	125.2	73.1						
12		6.25	8.00	124.8	72.8						
15		6.25	8.00	123.2	71.7						
18		6.25	8.01	122.7	72.3						
21		6.25	7.98	122.8	72.3						
24		6.25	8.00	122.4	73.2						
27		6.25	8.02	121.8	71.6						
30		6.25	7.90	121.5	70.5						
33		6.25	8.05	121.4	70.8						
36		6.25	8.00	120.8	70.0						
39		6.25	7.99	120.7	69.8						
42	.78	6.25	8.00	120.0	68.7						
Mean		6.25	8.00	123.4	72.0						

FIG. 21.—*Log sheet No. 6, gage board—welding*

Date 3-17-20
Computed by A.H.S.
Checked by L.T.W.

Sheet No. 7

Computations
Test No. 1-a

		Oxygen	Acetylene
Mean Line Pressure-	Lb. per Sq. In.	6.25	8.00
Line Drop-	Lb. per Sq. In.	.93	.65
Mean Torch Pressure-	Lb. per Sq. In.	5.32	7.35
Mean Atmosphere-	Lb. per Sq. In.	14.62	
Value of Flash Back Head-	Lb. per Sq. In.	.10	.10
Absolute Flow Meter Pressure-	Lb. per Sq. In.	20.97	22.72
Mean Potentiometer Reading-	Millivolts	.78	.78
Mean Temperature Factor-		1.000	1.006
Weight of Gas Used-	Pounds	3.812	2.620
Density of Gas-	Lb. per Cu. Ft.	.0890	.0742
Volume of Gas by Balance-	Cubic Feet	42.85	35.31
Mean Rate of Flow by Flow Meter-	Cu. Ft. per Hr.	58.21	49.5
Duration of Test .734 Hours			
Volume of Gas by Flow Meter-	Cubic Feet	42.75	36.3
Loss of Tank Pressure-	Lb. per Sq. In.	55	17
Cubic Feet per Pound of Tank Pressure-		.68	2.2
Volume of Gas by Test Gage-	Cubic Feet	37	37
Volume Ratio by Balance-		1.21	
Volume Ratio by Flow Meter-		1.18	
Length of Weld ~~or Cut~~ in Feet-		2.0	
Linear Feet per Hour Welded ~~or Cut~~-		2.72	
Mean Tank Pressure-	Lb. per Sq. In.		184.5

FIG. 22.—*Log sheet No. 7, computations—welding test No. 1-a*

Date 3-17-20
Computed by A.H.S.
Checked by L.L.W.

Sheet No. 7

Computations
Test No. 1-b

		Oxygen	Acetylene
Mean Line Pressure.	Lb. per Sq. In.	6.25	8.01
Line Drop.	Lb. per Sq. In.	.94	.60
Mean Torch Pressure.	Lb. per Sq. In.	5.31	7.41
Mean Atmosphere.	Lb. per Sq. In.	14.56	
Value of Flash Back Head.	Lb. per Sq. In.	.10	.10
Absolute Flow Meter Pressure.	Lb. per Sq. In.	20.91	22.67
Mean Potentiometer Reading.	Millivolts	.79	.81
Mean Temperature Factor.		.999	1.002
Weight of Gas Used.	Pounds	3.600	2.379
Density of Gas.	Lb. per Cu. Ft.	.0890	.0744
Volume of Gas by Balance.	Cubic Feet	40.45	32.00
Mean Rate of Flow by Flow Meter.	Cu. Ft. per Hr.	58.65	47.7
Duration of Test .686 Hours			
Volume of Gas by Flow Meter.	Cubic Feet	40.21	32.71
Loss of Tank Pressure.	Lb. per Sq. In.	55	14
Cubic Feet per Pound of Tank Pressure.		.68	2.2
Volume of Gas by Test Gage.	Cubic Feet	37	31
Volume Ratio by Balance.		1.26	
Volume Ratio by Flow Meter.		1.23	
Length of Weld ~~or Cut~~ in Feet.		2.0	
Linear Feet per Hour Welded ~~or Cut~~		2.91	
Mean Tank Pressure.	Lb. per Sq. In.		164

FIG. 23.—*Log sheet No. 7, computations—welding test No. 1-b*

Date 5-27-20
Computed by A.T.D.
Checked by M.L.C.

Sheet No. 1

Summary
of
Cutting Test No. 6a

Style of Torch C No. 1362

Manufactured by

Thickness of Cut 1/2 in. Length of Cut 20 ft.

Time Required to Make the Cut 13 min. 57 sec.

Linear Feet Cut per Hour 86.0

Type of Cut Secured:

Top Edge Smooth

Face of Cut Smooth

Drag 5/8 inch

Kerf 1/16 inch

Slag Brittle, slightly metallic slag. Clean bottom edge.

Pressure, Gas Consumption and Rate of Flow

	Oxygen	Acetylene
Mean Line Pressure - Lb. per Sq. In.	25.00	3.02
Mean Torch Pressure - Lb. per Sq. In.	24.70	2.98
Weight of Gas Used - Pounds	1.095	0.179
Volume in Cu. Ft. ~~per Hour~~ Determined From		
1. Weight of Gas Used	12.30	2.41
2. Flow Meter Data	12.2	2.4
3. Test Gage Readings	—	—
Mean Rate of Flow by Flow Meter	(52.9)[B]	(10.4)[B]
Cubic Feet per Hour	52.5	10.2

[B] By Balance.

FIG. 24.—*Log sheet No. 1, summary—cutting*

Date 5-27-20
Computed by A.H.S.
Checked by L.R.S.

Sheet No. 2

Summary
of
Test No. 6a

Record of Torch Consumption

Time Minutes	Rate of Flow Cu. Ft. per Hour Oxygen	Acetylene	Volume Ratio Oxy. : Acet.	Time Minutes	Rate of Flow Cu. Ft. per Hour Oxygen	Acetylene	Volume Ratio Oxy. : Acet.
1	53.6	11.8					
3	52.1	11.8					
Flame readjusted							
5	52.5	10.7					
7	51.6	11.1					
Flame readjusted							
9	53.4	9.1					
11	51.9	7.8					
13	52.0	8.7					

Remarks -

Fig. 25.—*Log sheet No. 2, summary—cutting*

Date 5-27-20
Recorder Waite
Observer

Sheet No: 3

Weighing Table Log Sheet
for
Cutting Test No. 6-a

Style of Torch G No. 1362

Manufactured by

Thickness of material cut ½ in Length of cut 2.0 ft Tip No. 1

Manufacturer's specified pressures:

Oxygen 25 lb. per sq. in. Acetylene 3 lb. per sq. in.

Pressure at which gas was delivered to torch line.

Oxygen 25 lb. per sq. in. Acetylene 3.02 lb. per sq. in.

Number of Gas Tanks in banks: Oxygen 7 Acetylene 3

Average Analysis of gas in bank: Oxygen 98.34 Acetylene (97.7)

Gases as determined by loss in weight of tanks:

Oxygen 496.4 grams Acetylene 81.1 grams

Time required to make cut 13 min. 57 sec.

Remarks:

FIG. 26.—*Log sheet No. 3, weighing table summary—cutting*

Date 5-27-20
Recorder Waite
Observer

Sheet No. 4

Log Sheet
Test No 6a

Style and No. of Torch C-1362
Mfg by
Operator R. L. W.

	Oxygen Scale Reading	Oxygen Zero	Acetylene Scale Reading	Acetylene Zero
Initial	16.52		37.84	
	8.96	12.66	29.10	33.42
	16.19	12.62	37.64	33.43
	9.14	12.59	29.36	33.46
	15.89		37.50	
True Zero		12.56		33.40
Final	16.60		30.07	
	8.84	12.65	37.79	33.98
	16.33	12.65	30.30	33.97
	9.12	12.67	37.50	33.95
	16.12		30.50	
		12.66		33.97
Displ. of Zero		-.10		-.47
Sensitivity		14.70		14.71
Value of Displ.		1.47		-6.91
Loss per minute		.073		.00
Time		13'-57"		13'.95"
Value of Loss		-.103		
Total Correction		-1.57		-6.91

	Oxygen	Acetylene
Replacement Weight	498.0	88.0
Correction	-1.6	-6.9
True Weight	496.4	81.1

FIG. 27.—*Log sheet No. 4, weighing table—cutting*

Date 5-27-20
Recorder Deming
Observer Deming - Sweetman.

Sheet No. 5

Gage Board
Log Sheet
for
Cutting Test No. 6-a

Torch manufactured by ____ Operator R.L.W.

Thickness of plate cut $\frac{1}{2}$ in. Length of cut 20 ft Tip No. 1

Manufacturer's specified pressure:

Oxygen 25 lb. per sq. in. Acetylene 3 lb. per sq. in.

Pressure at which gas was delivered to torch line:

Oxygen 25 lb. per sq. in. Acetylene 3.02 lb. per sq. in.

Tank Pressures:	Oxygen lb. per sq. in.	Acetylene lb. per sq. in.
At start	1095	262
At end	1080	260

	Temperature (Room)	Barometer	Humidity
At start	72.1	753.0	.89
At end	73.5	752.5	.89

Position of manometers: High —— Low A Vertical O

Orifice No. Oxygen V Acetylene IV

Temperature reading of orifice:	Oxygen	Acetylene
At start	.80 m.v.	.82 m.v.
At end	.80 m.v.	.82 m.v.

Time required to make cut 13 min. 57 sec.

Remarks 2.7 high gear. No resistance.

FIG. 28.—*Log sheet No. 5, gage board summary—cutting*

Date 5-27-20 Sheet No. 6
Recorder Deming
Observer Deming-Sweetman.

Pressure and Flow Meter Log Sheet
for
Cutting Test No. 6-a

Torch manufactured by

Thickness of plate cut ½ in Length of cut 20 ft. Tip No. 1

Pressure at which gas was delivered to torchline:

Oxygen 25 lb. per sq. in. Acetylene 3.02 lb. per sq. in.

Time	Poten.	Pres. at Reg. Oxygen	Pres. at Reg. Acety.	Flow meter differentials Oxygen	Flow meter differentials Acety	Time	Poten	Pres at Reg Oxygen	Pres at Reg Acety.	Flow Meter differentials Oxygen	Flow Meter differentials Acety.
1	80	25.00	3.00	55.4	32.2						
3		25.05	2.90	52.3	32.3						
		Flame readjusted									
5		24.95	3.05	53.2	26.6						
7		25.00	2.98	51.4	28.4						
		Flame readjusted.									
		Flame readjusted									
9		25.00	3.20	55.0	19.2						
11		25.00	3.00	52.0	14.0						
13	80	25.00	3.00	52.1	17.4						
Mean		25.00	3.02	53.1	24.3						

FIG. 29.—*Log sheet No. 6, gage board—cutting*

Date 5-27-20
Computed by T.W.G.
Checked by E.R.B.

Sheet No. 7

Computations
Test No. 6-a

		Oxygen	Acetylene
Mean Line Pressure-	Lb. per Sq. In.	25.00	3.02
Line Drop-	Lb. per Sq. In.	.20	.04
Mean Torch Pressure-	Lb. per Sq. In.	24.70	2.98
Mean Atmosphere-	Lb. per Sq. In.	14.56	
Value of Flash Back Head-	Lb. per Sq. In.	.00	.10
Absolute Flow Meter Pressure-	Lb. per Sq. In.	39.56	17.68
Mean Potentiometer Reading-	Millivolts	.80	.82
Mean Temperature Factor-		.999	1.003
Weight of Gas Used-	Pounds	1.095	.179
Density of Gas-	Lb. per Cu. Ft.	.0890	.0743
Volume of Gas by Balance-	Cubic Feet	12.30	2.41
Mean Rate of Flow by Flow Meter-	Cu. Ft. per Hr.	52.5	10.2
Duration of Test .232 Hours			
Volume of Gas by Flow Meter-	Cubic Feet	12.18	2.37
Loss of Tank Pressure-	Lb. per Sq. In.	15	2
Cubic Feet per Pound of Tank Pressure-		—	—
Volume of Gas by Test Gage-	Cubic Feet	—	—
Volume Ratio by Balance-		—	
Volume Ratio by Flow Meter-		—	
Length of ~~Weld or~~ Cut in Feet-		20	
Linear Feet per Hour ~~Welded or~~ Cut-		86	
Mean Tank Pressure-	Lb. per Sq. In.	261	

FIG. 30.—*Log sheet No. 7, computations—cutting*

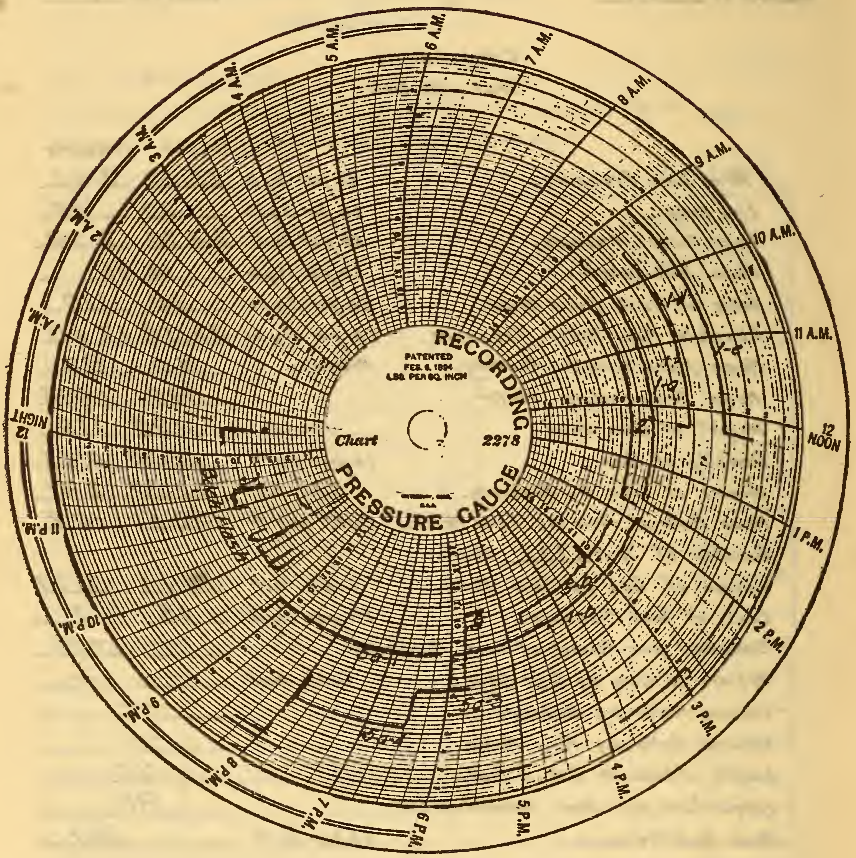


FIG. 31.—*Pressure gage record showing closeness of pressure control*

For certain studies on the probable economies of operation of the various blowpipes it was necessary to assume certain fixed values as units of compensation and cost. While this procedure may be open to certain criticisms due to the fact that the assigned values are arbitrary and may not apply under conditions of operation ordinarily met with in commercial work, still it is only through such economy studies that certain features of blowpipe operation can be distinctly shown. For such studies the standard salary schedule of the United States Naval Gun Factory, Washington, D. C., for the summer of 1920 was selected as the basis of compensation for labor costs. On this assumption the labor costs for welding and cutting have been computed at 80 cents per man-hour. For specifying the value of the gas consumed during any particular operation the prices of $1.50 per hundred cubic feet for tanked oxygen and $2.75 per hundred cubic feet for tanked acetylene were assumed. The prices are those at which such gases were furnished to the Bureau and seem on the whole to represent general average costs for such commodities, exclusive of shipment charges. An unsuccessful attempt was made to secure what might be considered general average prices from several of the larger gas manufacturers. Before definitely settling on the above prices, cost data for several of the test series were computed for varying ratios of cost of oxygen to acetylene. These latter figures showed that any reasonable change in the basis of cost caused only a few unimportant changes in the relative rating of the blowpipes.

In the computations of cost of operation only gas and labor costs are included. No additions have been made for maintenance of equipment, overhead charges, and secondary supplies. It is felt that this procedure furnishes a satisfactory basis of analysis, as external conditions and management will largely control the value of secondary costs and vitiate any assumptions made concerning the value of such items.

Certain of the plotted data mentioned above contain curves showing the relative velocity of exit of gases from the blowpipe tips. In order to plot these curves for the cutting blowpipes it was assumed that the volume of oxygen consumed by the preheating flames was equal to the measured volume of acetylene consumed, and that the volume of oxygen available for the oxygen cutting jet was therefore the total measured volume of

oxygen consumed, minus an amount equal to the measured volume of acetylene consumed. For the welding blowpipes the velocity of exit was based upon total volume of both gases consumed.

2. THE CUTTING BLOWPIPE

The summaries of the data obtained from cutting tests made with the various blowpipes are shown in Figs. 32 to 41 and Table 3. The curves of Figs. 32 to 35 are plotted to show, for the thickness of metal used for the tests, the relations existing between the volumes of oxygen and acetylene consumed per hour, the linear feet of metal cut per hour, and the velocity of exit of the oxygen cutting jet. A study of these curves shows that the rate of cutting apparently increases with the volume of oxygen consumed. In these curves the blowpipes are arranged in the order of the oxygen consumption.

For determining the relative economy of operation the graphs of Figs. 36 to 39 have been plotted to show the cost per linear foot of cut for each blowpipe. In these curves the blowpipes have been arranged in the order of the cost of operation.

The study of these data shows some rather interesting conditions relative to the art of metal cutting by the oxyacetylene process:

1. The very great irregularity in the shape of the various graphs indicates quite clearly that if the individual blowpipes have been designed according to a theory there does not exist any generally accepted theory. It is interesting to note in this connection that in cutting identical material under standardized conditions the various blowpipes exhibit, as indicated by the data for cutting ½ inch metal (Fig. 32), variations in speed of cutting from 33 to 109 feet per hour, or 330 per cent; variations in volume of oxygen consumed from 30 to 130 cubic feet per hour, or 430 per cent; variations in velocity of exit of cutting jet oxygen from 530 to 1975 feet per second, or 390 per cent; and variations in volume of acetylene consumed from 7 to 21 cubic feet per hour, or 300 per cent.

FIG. 32.—*Relation of rate of flow and velocity of exit of oxygen to rate of cutting ½-inch metal*

FIG. 33.—*Relation of rate of flow and velocity of exit of oxygen to rate of cutting 2-inch metal*

FIG. 34.—*Relation of rate of flow and velocity of exit of oxygen to rate of cutting 6-inch metal*

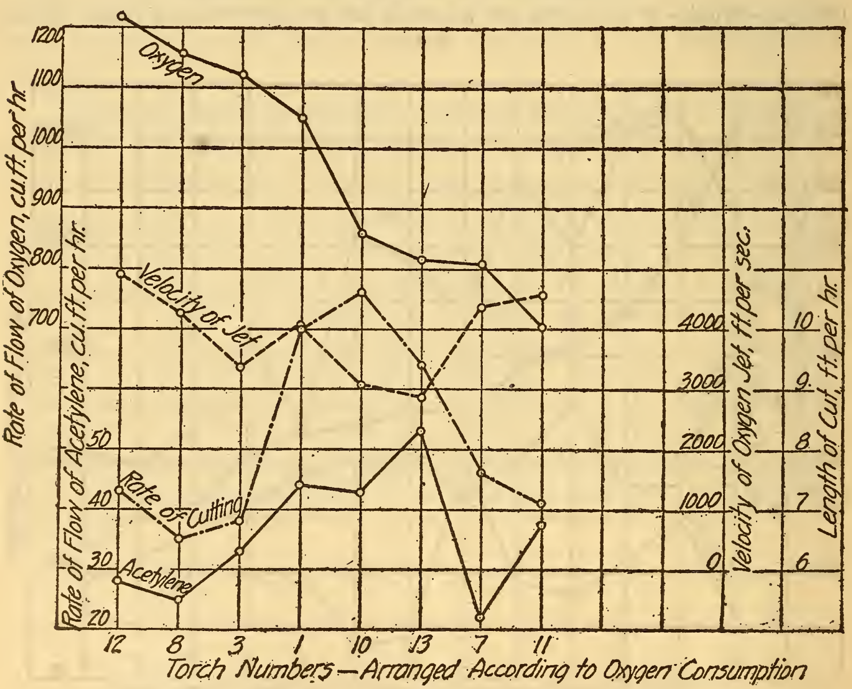


FIG. 35.—*Relation of rate of flow and velocity of exit of oxygen to rate of cutting 10-inch meta l(see footnote d, Table 3)*

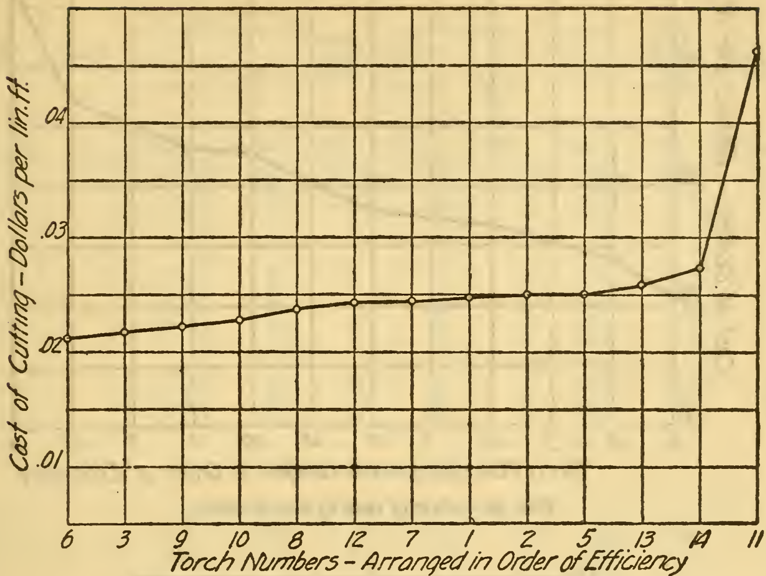


FIG. 36.—*Cost of cutting ½-inch metal*

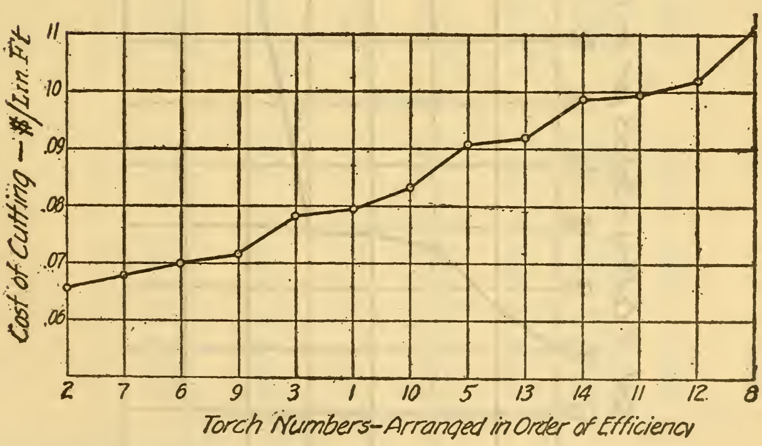


FIG. 37.—*Cost of cutting 2-inch metal*

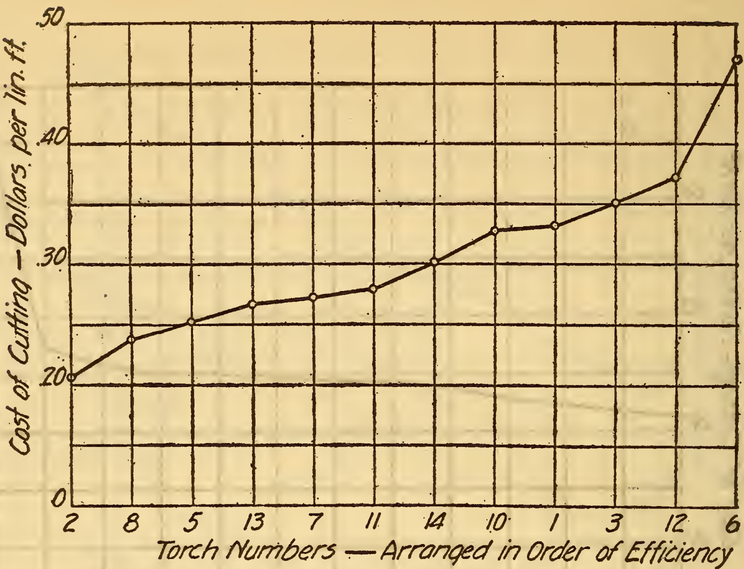


FIG. 38.—*Cost of cutting 6-inch metal*

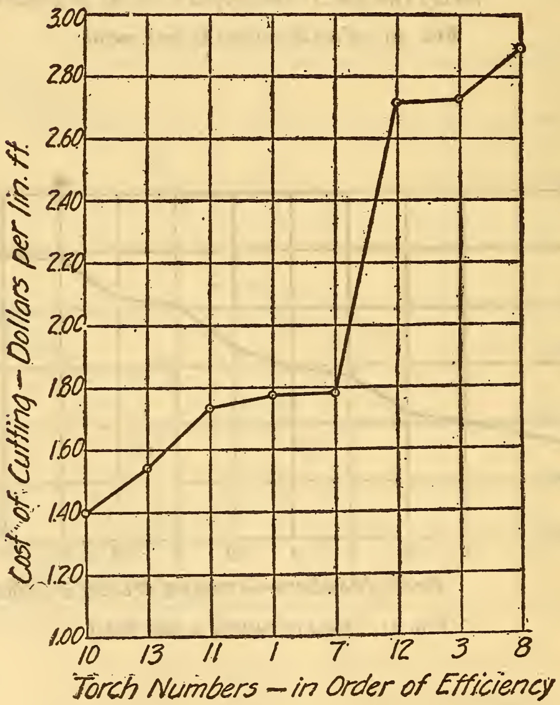


FIG. 39.—*Cost of cutting 10-inch metal (see footnote d, Table 3)*

TABLE 3.—General Summary of Cutting-Torch Data

Test 6—½-inch material

Torch No.	Tip No.	Pressure delivered at torch handle: Oxygen	Pressure delivered at torch handle: Acetylene	Length cut per hour	Volume consumption: Oxygen	Volume consumption: Acetylene	Velocity of oxygen jet	Length cut per cubic foot of oxygen	Cost per linear foot cut
		Lbs./in.²	Lbs./in.²	Feet	Ft.³/hr.	Ft.³/hr.	Ft./sec.	Feet	Dollars
[a] (1)	[a] (2)	[a] (3)	[a] (4)	[a] (5)	[a] (6)	[a] (7)	[a] (8)	[a] (9)	[a] (10)
1..........	2	19.32	3.95	90	74	12	1975	1.45	0.025
2..........	1	14.79	2.98	63	37	8	922	2.17	.025
3..........	1	24.70	2.98	86	53	10	1184	2.00	.022
4 [b]........	....	....	....	....	....	....	....	....	....
5..........	2	9.53	4.97	73	50	10	752	1.82	.025
6..........	2	19.21	2.98	102	77	8	1010	1.48	.021
7..........	1	29.69	4.94	81	55	13	1272	1.93	.024
8..........	1	24.52	5.90	98	70	20	1180	2.00	.024
9..........	3	39.74	4.98	84	59	7	1502	1.61	.022
10..........	1	24.68	6.97	87	57	12	1364	1.93	.023
11..........	1	5.74	1.94	33	31	9	530	1.50	.046
12..........	2	11.04	1.99	88	74	9	834	1.35	.024
13..........	1	24.82	.88	79	51	17	1139	2.32	.026
14..........	2	28.34	1.72	109	130	8	1564	.89	.027

Test 7—2-inch material

Torch No.	Tip No.	Pressure delivered at torch handle: Oxygen	Pressure delivered at torch handle: Acetylene	Length cut per hour	Volume consumption: Oxygen	Volume consumption: Acetylene	Velocity of oxygen jet	Length cut per cubic foot of oxygen	Cost per linear foot cut
1..........	2	56.05	3.96	45	163	13	2523	0.300	0.079
2..........	2	42.70	2.97	46	134	8	1842	.366	.066
3..........	3	37.10	4.86	57	210	20	1814	.300	.078
4 [b]........	....	....	....	....	....	....	....	....	....
5..........	3	23.08	4.95	26	87	11	863	.342	.091
6..........	3	48.09	3.89	55	175	16	1805	.346	.070
7..........	2	53.70	4.93	51	154	14	2050	.364	.068
8..........	2	44.83	3.91	28	130	15	1934	.243	.111
9..........	4	58.97	5.99	44	139	9	2188	.338	.072
10..........	2	33.84	4.92	37	123	15	1580	.342	.083
11..........	2	28.95	2.90	28	104	15	1302	.314	.099
12..........	2	21.91	2.97	25	98	10	1129	.284	.102
13..........	2	44.26	.72	39	140	25	1683	.339	.092
14..........	3	45.91	1.95	48	243	11	2979	.207	.099

Test 8—6-inch material

Torch No.	Tip No.	Pressure delivered at torch handle: Oxygen	Pressure delivered at torch handle: Acetylene	Length cut per hour	Volume consumption: Oxygen	Volume consumption: Acetylene	Velocity of oxygen jet	Length cut per cubic foot of oxygen	Cost per linear foot cut
1..........	4	74.70	4.02	29	546	25	2865	0.056	0.332
2..........	3	72.60	4.91	27	285	15	2260	.100	.206
3..........	4	75.83	5.74	27	517	30	2532	.055	.350
4 [b]........	....	....	....	....	....	....	....	....	....
5..........	4	....	6.96	20	256	15	1824	.083	.253
6..........	5	82.20	3.91	18	479	16	2455	.039	.478
7..........	3	90.60	9.88	26	378	23	2970	.073	.273
8..........	3	69.99	3.90	27	342	16	2466	.083	.238
9 [c]........	....	....	....	....	....	....	....	....	....
10..........	4	72.38	3.84	24	441	21	1589	.057	.327
11..........	3	103.20	6.83	26	360	36	3365	.080	.280
12..........	4	67.39	3.63	13	241	18	2861	.058	.372
13..........	3	79.30	.25	29	388	41	2904	.084	.267
14..........	4	70.10	3.42	27	463	14	3761	.060	.301

[a] Numbers in parentheses are column numbers.
[b] Not submitted to cutting tests.
[c] Torch failed to cut in this test.

TABLE 3—Continued

Test 9—10-inch material

Torch No.	Tip No.	Pressure delivered at torch handle: Oxygen	Pressure delivered at torch handle: Acetylene	Length cut per hour	Volume consumption: Oxygen	Volume consumption: Acetylene	Velocity of oxygen jet	Length cut per cubic foot of oxygen	Cost per linear foot cut
		Lbs./in.^{2}	Lbs./in.^{2}	Feet	Ft.^{3}/hr.	Ft.^{3}/hr.	Ft./sec.	Feet	Dollars
[a] (1)	[a] (2)	[a] (3)	[a] (4)	[a] (5)	[a] (6)	[a] (7)	[a] (8)	[a] (9)	[a] (10)
1	5	129.80	5.73	10.0	1050	44	4012	0.0100	1.776
2 [b]									
3	5	123.90	7.68	6.8	1122	33	3385	.0064	2.725
4 [c]									
5 [b]									
6 [b]									
7	4	153.00	11.88	7.6	809	22	4350	.0102	1.780
8	4	165.70	3.79	6.5	1157	25	4281	.0053	2.898
9 [b]									
10	4	152.90	14.65	10.6	858	43	3085	.0135	1.400
11	4	164.17	4.63	7.1	701	37	4565	.0106	1.737
12	6	160.24	5.73	7.3	1216	28	4912	.0058	2.716
13	4	117.32	−.69	9.4	816	53	2889	.0117	1.542
14 [b] [d]									

[a] Number in parentheses are column numbers.
[b] Torch failed to cut in this test.
[c] Not submitted to cutting tests.
[d] By inadvertent error a No. 4 tip was used instead of a No. 8*a* in making the 10-inch cut reported on above. On a previous test with an 8*a* tip torch No. 14 made a cut through 10-inch material using an oxygen velocity of 7310 feet per second; consuming 1340 cubic feet of oxygen and 18.55 cubic feet of acetylene per hour; cutting at the rate of 9.23 feet per hour at a cost of $2.32 per linear foot of cut, which is at the rate of 0.0067 foot of cut per cubic foot of oxygen. The cut was of fair quality.

2. In general the speed of cutting increases with the volume of oxygen consumed, provided the velocity of exit of the cutting jet and the amount of acetylene consumed in the preheating flame is kept constant.

3. With the same velocity of exit of cutting jet and equal oxygen consumption the speed of cutting is reduced and therefore the cost of operation increased by an increase in the amount of acetylene consumed in the preheating flames, the increased amount of acetylene requiring a larger amount of oxygen for its combustion and thus decreasing that available as an oxidizing agent in the cutting jet.

4. With equal acetylene consumption and equal oxygen consumption the rate of cutting and therefore the decrease in cost of operation increases with the velocity of exit of the oxygen-cutting jet, up to a certain limit. Beyond this limit a further increase does not further decrease the cost of operation.

5. With equal acetylene consumption, increasing the velocity of exit of the oxygen jet and at the same time the oxygen consumption does not necessarily increase the speed of cutting in commensurate ratio and may even tend toward increased cost of operation. It seems apparent that there is an economical limit to such increases, and that with too high a velocity an

increased oxygen volume may be wasted. This indicates that for any thickness of metal there is a limiting velocity at which complete utilization of the oxygen takes place and a limiting value to the amount of oxygen required to produce the cut.

As indicated above there is a great deal of difference between the characteristics of blowpipes of different designs. One of the most interesting and noticeable differences is the fact that no make is equally proficient and economical for all thicknesses of metal. Of the six most economical cutting blowpipes on ½-inch material, two failed to cut 10-inch material, and the remainder stand almost in the inverse order of rating. Further, two of the most uneconomical blowpipes on ½-inch material are two of the most economical on the heavy or 10-inch cutting. It is interesting to note that this reversal of performance in general seems to be progressive with the variation in thickness of metal cut. (See Table 3 and Figs. 36 to 39.)

The reason for reversal of performance, upon examination of the data available, seems to be quite clearly indicated. The average design of blowpipe is operated with the oxygen jet issuing from the tip at too great a velocity. It will be noted that the most efficient blowpipes for the metal of various thicknesses are those operating at the lower velocities. Where there appears to be a divergence from this fact it will be further noted that those blowpipes seeming in performance to be inconsistent with the above statement are those using an excessive amount of acetylene.

A portion of the data of Table 3 replotted to show the relation between area of metal cut per cubic foot of oxygen consumed for the various thicknesses (See Fig. 40) is of further interest, as it suggests that none of the blowpipes submitted to test are as economical in cutting 2-inch and possibly 10-inch metal as might be expected. The data of Fig. 40 show distinctly that the amount of metal cut per cubic foot of oxygen was greatest for the ½-inch material. Further, if the oxygen in all cases could be used with the same economy, and the same width of kerf as obtained with the ½-inch material secured for metal of various thicknesses, the relation between square inches of metal cut per cubic foot of oxygen used and the various thicknesses would lie on a horizontal straight line (*a–a* Fig. 40) through the point of maximum efficiency for the ½-inch material. The replotted data, however, lie below this straight line.

It should be expected that in reality the width of kerf would increase with the thickness being cut, and on this basis it is evident

that a curve representing the relation between the area of metal cut per unit volume of oxygen consumed and the thickness would be a smooth regular curve falling constantly further below the line *a–a* with the increased thickness of metal cut. Further, such a curve would either approach parallelism with the horizontal axis or actually cut it at some definite point.

The law governing this relation has not been determined during this investigation. It is possible that there is a certain minimum kerf required for cutting thin metal, and accepting this with the further assumption that beyond this minimum kerf the width of kerf increases linearly with the thickness cut, the law of variation

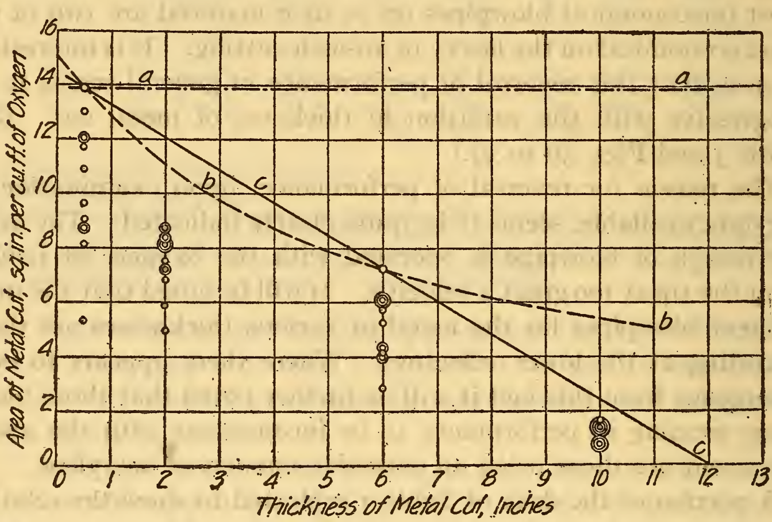


Fig. 40.—*Variations in efficiency of blowpipes for cutting metal of different thicknesses*

between area of metal cut for unit volume oxygen consumption and the thickness of metal cut would be expressed by a curve of the form indicated by the line *b–b*. If further it is assumed that the cuts for ½ and 6 inch metal were probably as nearly as economical as it is possible to secure them, this curve would actually occupy the position at which it is shown on the sheet.

A more simple assumption can, however, be made—that is, that the above relation is expressed by a sloping straight line, and it is of interest to note that such a line *c–c* can actually be passed nearly through all the points of maximum economy plotted on the sheet.

On either of these assumptions it is very evident that none of the blowpipes tested are cutting 2-inch material economically. It would seem that the reason for this noneconomy of operation

is probably due to two things. First, the use of an oxygen cutting jet issuing at too great a velocity. If a velocity of 2200 feet per second is sufficient for cutting 6-inch material, it would appear that a velocity of 1800 feet per second is excessive for 2-inch material. Secondly, in the blowpipes tested the preheating flames in most cases were too large for the work required. In fact, in a number of instances there was practically very little difference between the size of the preheating flame used for the 2-inch plate and that used for the 6-inch material. For the thinner material the large-sized preheating flame would tend toward noneconomy in operation inasmuch as it would preheat a relatively large surface, with the resulting tendency for the oxygen to oxidize the entire body of metal thus preheated, giving probably a wider kerf than necessary and thus using the oxygen supply nonadvantageously. This conclusion is further substantiated by the fact that in cutting 2-inch material practically none of the slags showed metallic characteristics but were on the other hand fully oxidized metal.

A further study of the data presented in Fig. 40 indicates also that possibly the maximum economy has not been fully secured for the 10-inch material. It is certain, though, in this connection that the relation between metal cut per unit volume of oxygen consumed and metal of different thicknesses can not follow the law suggested and represented by the curve *b–b*, for this curve implies that, in addition to a possible increase in economy over that actually obtained, far greater thicknesses could be cut with relatively slight changes in economy. This is contrary to known facts and is rather forcibly contradicted by the appearance and character of the cuts made on 10-inch material and shown in Figs. 44 to 46, inclusive. It seems probable, then, that the true economy relation is more nearly represented by the straight line *c–c*. If this is true, then a slight improvement might be expected in cutting 10-inch material economically. On the other hand, such a conclusion leads directly to the fact that the maximum available cut of oxyacetylene blowpipes of present design lies in the vicinity of 12 inches. As an interesting side light on this, Fig. 47 shows an attempted cut for maximum thickness made with the blowpipe that exhibited maximum efficiency in heavy cutting. The cut penetrated about 12 inches into a 16-inch block, the bottom of the cut being practically at right angles to the direction of cut.

This immediately brings up the question as to why the limit of depth of cut for an oxyacetylene blowpipe should apparently be about 12 inches. It has been known that in heavy cutting the cleaner cuts and greater depths were secured with the oxyhydro-

gen blowpipe. (See Fig. 46*B*.) The reason generally given for this difference is that the oxyhydrogen preheating flame is longer and therefore secures better preheat penetration within the cut. It would seem, however, that a possibly more probable explanation of the difference lies in the resulting products of combustion and that this is also a possible explanation of the limitation of the oxyacetylene blowpipe in heavy cutting. Besides the iron oxide, water vapor and carbon dioxide are formed during the cutting process. With the use of acetylene instead of hydrogen a greater proportion of carbon dioxide is formed. This gas sinking to and being partially trapped in the lower portion of a cut and being a nonsupporter of combustion causes a slackening of the oxidation process and in deep cuts it may be present in sufficient volume to actually arrest the oxidation process. This suggestion would seem to be verified by the experience that in deep cutting a large increase in the kinetic energy of the issuing cutting jet produced by increasing the pressure at which the gas is used will often secure a cut where the blowpipe would otherwise not have been enabled to do so. The increased pressure and resulting energy insures that the products of combustion are blown out of the way. Under such conditions increased depths of cuts may be secured, but not necessarily economically.

Unfortunately these questions have not been definitely settled by these tests and the above must therefore be looked upon simply as indications and suggestions for further work toward securing increased economy in cutting.

In questions of economy of operation the volume of gas used plays an important part. Where an excessive amount of acetylene is used, acetylene being the more expensive gas, the economy of operation is affected adversely. This question of acetylene consumption is one that would seem to deserve attention. The size of the preheating flames is a direct index of the acetylene consumption. As indicated above in a great many of the blowpipes tested, it was found necessary to reduce the acetylene pressure under that specified by the manufacturer (thereby reducing the size of the flame or acetylene consumption) in order to secure the flame size that did not melt too much of the top edge of the cut and reunite the pieces cut apart by the flow of this molten metal back into the kerf. In some instances with the specified preheating flame the pieces were practically welded together again along the top edge, and in others the top edge was badly beveled.

Neither of the above conditions, developed by excessive sized preheating flames, is desirable. Even though not welded together a badly beaded top edge (Fig. 43*H*) or a badly beveled top edge would in most cases increase the cost of following manufacturing operations. The feeling of the blowpipe manufacturers on this matter seems to be that they must have excessive preheating flames to take care of heavy scale, slag, etc., and to facilitate rapid cutting, especially at the start of a cutting operation. The experience of this investigation as developed on cutting does not indicate that a cut can be started any quicker with an excessive flame than with one of proper size. In cases where slag or heavy scale are met with it is doubted whether burning slag and scale

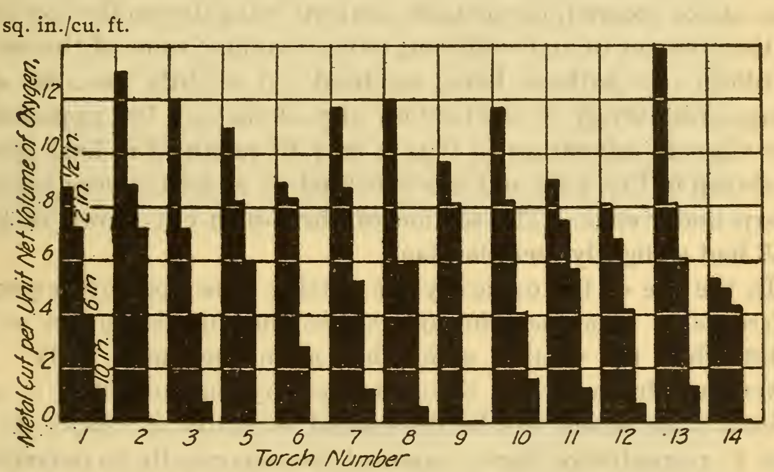


Fig. 41.—*Relation of volume of oxygen used to area of metal cut for metals of varying thicknesses*

off at an oxygen cost of $1.50 to $10 an hour (according to thickness of material cut) can economically compete with unskilled hand labor (chisel and hammer) at 75 cents per hour.

The quality of cut secured is quite important. Figs. 42 and 43 are included to show what may be expected from a properly operating cutting blowpipe. Figs. 44 to 46*A* attempted cuts on 10-inch material, in this case armor plate, speak for themselves, and they may well be taken to indicate that none of the blowpipes tested are suitable for working to close limits on cuts of such depths. For comparison an oxyhydrogen cut on the same block is shown in Fig. 46*B*.

On the other hand, there is splendid evidence that some blowpipes can do especially nice work when properly designed for the thickness being cut, in this case 6 inches. (Fig. 43*F*). A sec-

tional view through this cut is shown on the right-hand side of Fig. 48, *c*. Fig. 42 *B* to *E* inclusive shows typical cuts of 2-inch and ½-inch metal, and Fig. 42*A* is further evidence that there is such a thing as using too much oxygen in executing a cut.

Besides the top edge and face of a cut, the bottom edge is of interest, as its appearance is quite closely connected with the type of slag formed. A completely oxidized slag has a greater tendency to cling to the underside and if excess oxygen is present there is considerable undercutting which tends to increase the amount of slag and to make it adhere more firmly, with the result that a rough bottom edge is produced. By the proper proportioning of the oxygen volume it is apparent that a slightly metallic slag can be secured, the metallic element being due to the fact that in the presence of an insufficient oxygen volume some of the metal is blown out without being oxidized. A slightly metallic slag clings quite firmly to the bottom edge of the cut, but apparently possesses an advantage in that it may be removed in long pieces as shown in Fig. 43*G*, and leaves behind it, as seen, a very smooth sharp under edge. The section of the 6-inch cut shown in Fig. 43*F* had a slightly metallic slag.

In the use of the oxyacetylene cutting blowpipe with especial reference to manufacturing operations the question arises as to what effect the cutting action has upon the metal body. To determine this a section through oxyacetylene cuts of ½, 2, and 6 inch plate which will be designated hereafter as blocks A, B, and C, respectively, were examined microscopically to determine the nature and extent of the surface changes induced in the metal by the oxyacetylene flame used for cutting the blocks. The examination included a study of the macroscopic appearance of a cross section after suitable etching, as well as of the comparative microstructure of the central or unchanged portion of the blocks and of the surface metal. In the following macrographs (Fig. 48) the specimens are shown natural size, the surface having been etched with an aqueous solution of ammonium persulphate. The depth to which the material has been affected by the flame is readily detected.

All of the micrographs of the material were taken at a magnification of 100 diameters, after etching with 2 per cent alcoholic nitric acid. These have been designated as A, B, and C to correspond to the macrograph of the same material. The micrographs in Fig. 49, *A*, *B*, and *C* show the structural condition at the extreme edge of the section, that is, where the flame affected

FIG. 42.—*Oxyacetylene cuts on ½-inch and 2-inch steel*

FIG. 43.—*Oxyacetylene cuts on 6-inch steel*

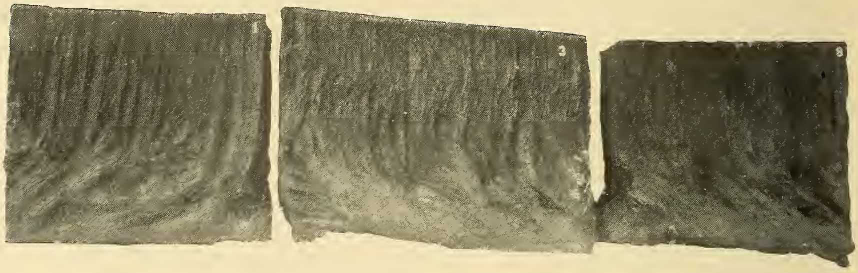


FIG. 44.—*Oxyacetylene cuts on 10-inch steel showing irregularity of cut*

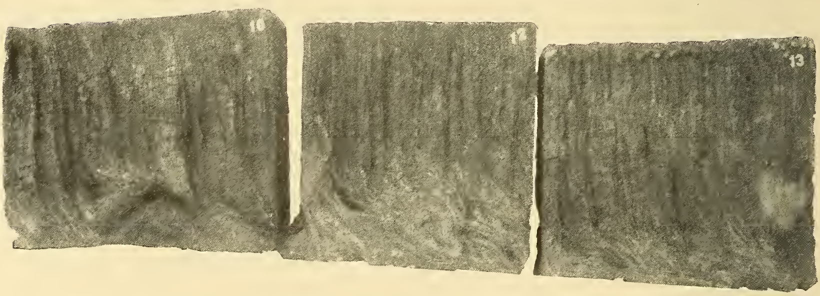


FIG. 45.—*Oxyacetylene cuts on 10-inch steel showing irregularity of cut*

FIG. 46A.—*Oxyacetylene cuts on 10-inch steel showing failure to complete cut*

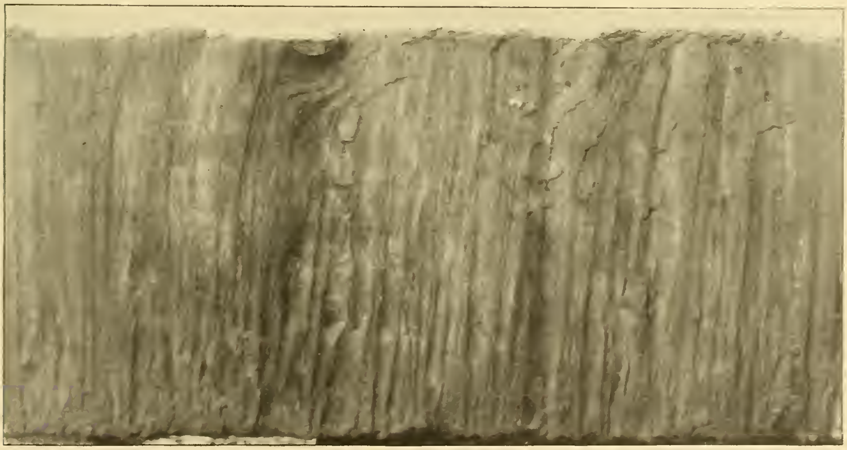


FIG. 46B.—*Oxyhydrogen cut on 10-inch steel showing relative smoothness of cut*

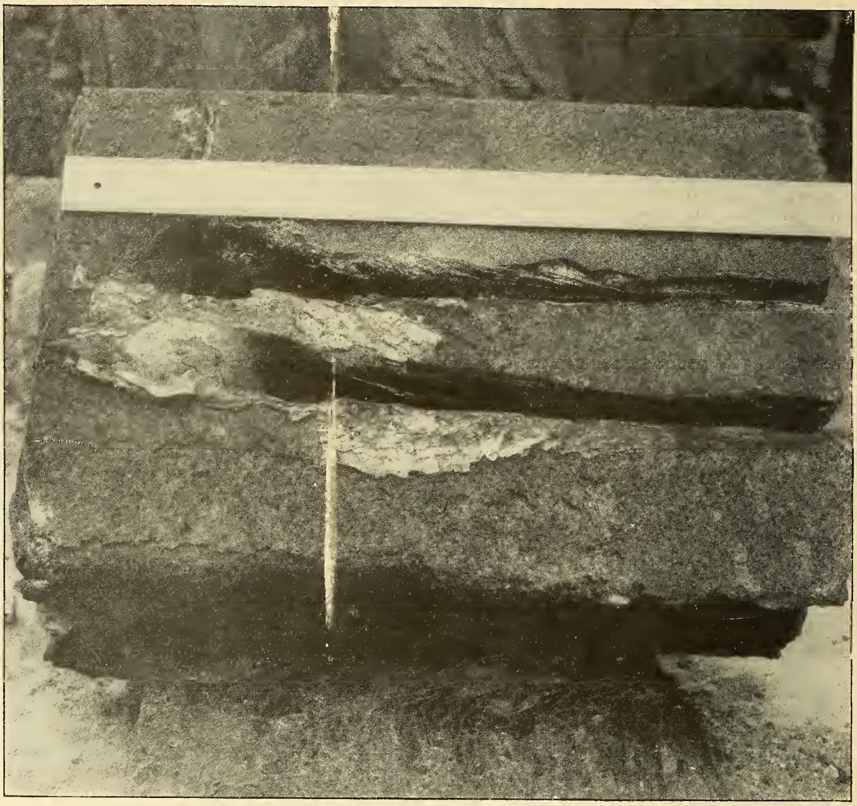


FIG. 47.—*Oxyacetylene cut on 16-inch steel showing failure of cut at depth of 12 inches*

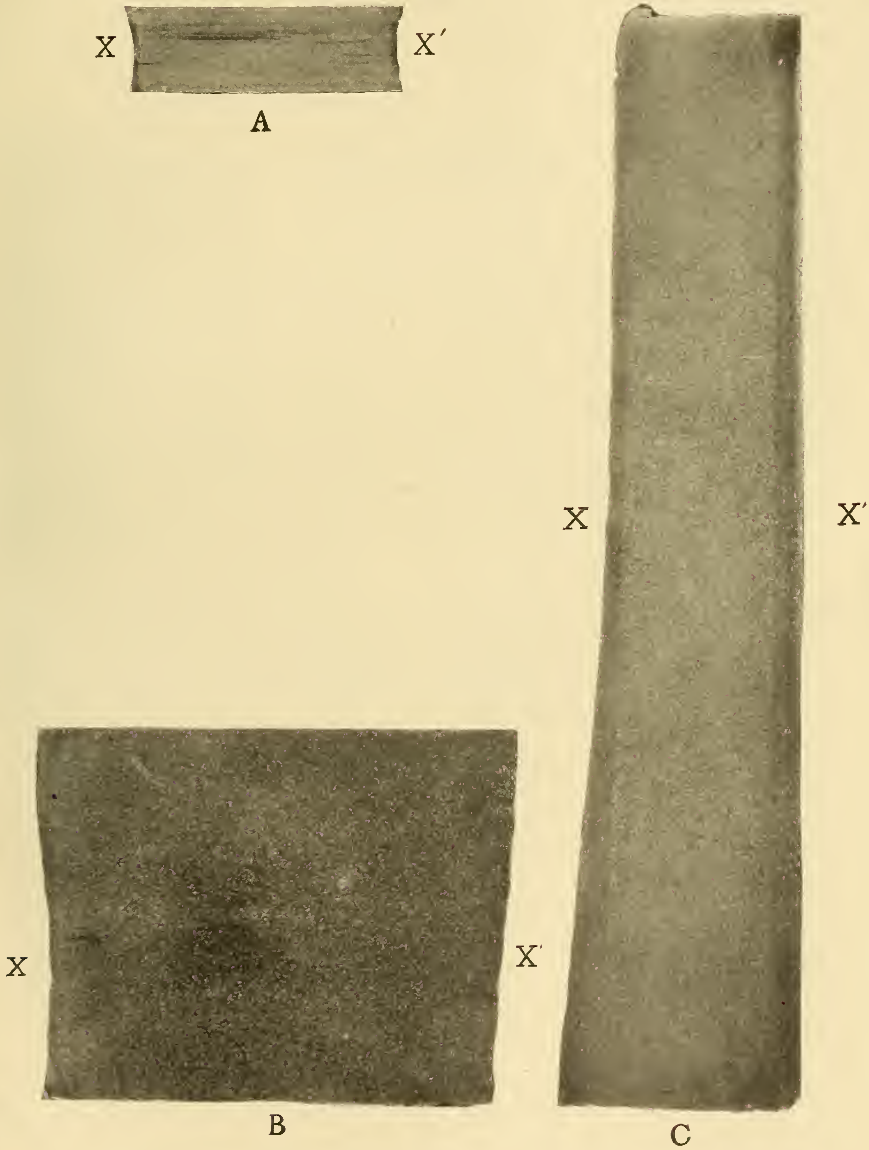
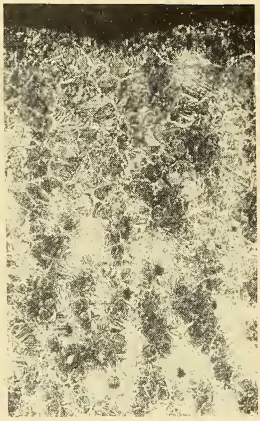
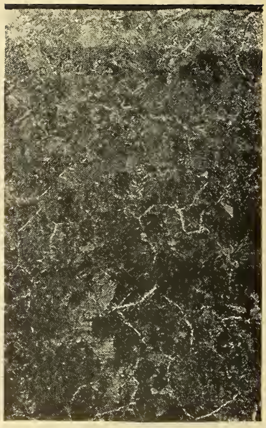


FIG. 48.—*Macrographs of ½-inch metal (A), 2-inch metal (B), and 6-inch metal (C) cut during tests. X and X′ are the sides exposed to the flame*

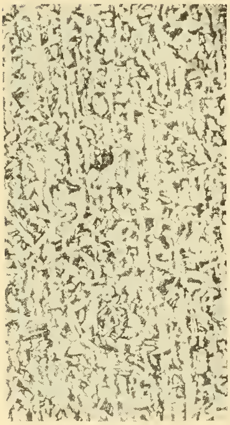
A



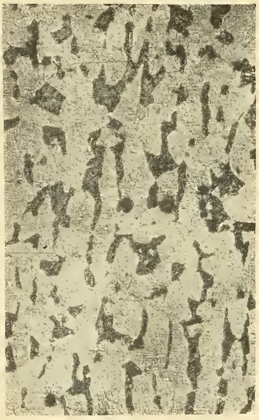
B



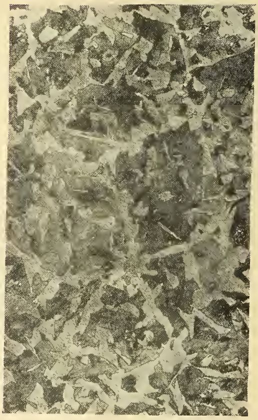
C



A′



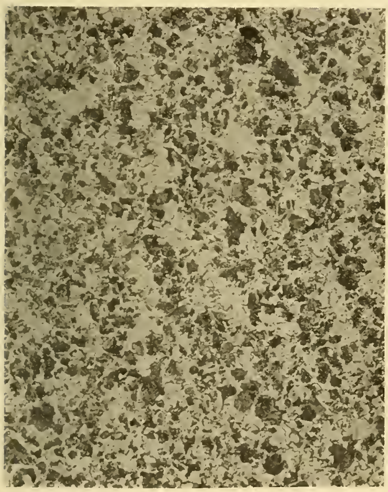
B′



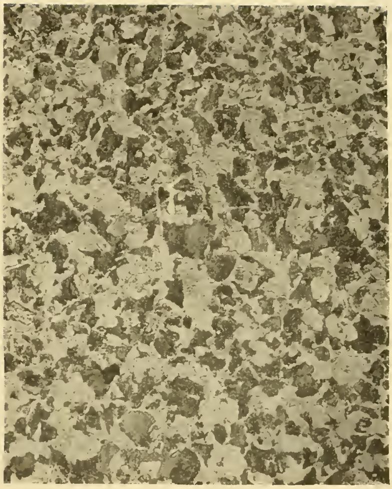
C′

FIG. 49 A, B, C.—*Surface exposed to the oxyacetylene flame*

FIG. 49 A′, B′, C′.—*Unchanged or initial structure of central portion of specimen*



C



C′

FIG. 50.—*Micrographs showing the structure of the outer C and central C′ portions of the specimen which seemed to be most affected by the cutting process as shown in Fig. 49*

the metal, and A', B', and C' show the initial or unchanged metal of the central part of the block. The three specimens vary considerably in their carbon content, and the magnitude of the change in the surface metal of the specimen of highest carbon content (specimen C) has been much greater than in the others which were of lower carbon content.

In order to determine whether there had been appreciable carburization of the surface metal, such as the micrographs suggest, a sample of specimen C, which material was affected to the largest extent, was annealed at approximately 760° C, that is, above its critical temperature. Proper means were taken to avoid decarburization during the heating. The micrographs in Fig. 50 show the structure of the outer (affected) layer, *C*, and the central portion C', at 100 diameters.

There appears to be no appreciable difference in the carbon content of the two parts of the annealed specimen. It may be concluded then that the appearance of the surface layer of the steel directly after cutting with the oxyacetylene flame is due to the chilling action of the large mass of unheated metal upon the hot surface after the flame has been removed. Such an effect would, of course, be more noticeable in a steel of higher carbon content than in one which is lower in this element. This of course accounts for the hard surface metal that is frequently encountered in working up metal cut with the oxyacetylene blowpipe.

A very noticeable feature in cutting blowpipe performance was the irregularity of action and the variation in length of the preheating flames and the frequency with which certain blowpipes developed flashbacks or went out during operations. In fact one particular and very well known blowpipe after six official test trials on ½-inch plate failed to make more than 43 feet of the required 50-foot test cut. As the causes back of these troubles are identical with the action of the welding blowpipes, discussion concerning them will be included in that on welding blowpipes.

Among the cutting tests there were included short lengths of cuts made on ½-inch plate with oxygen pressures set 50 and 25 per cent above the manufacturers' specified pressures and 25 and 50 per cent below them. As these tests, outside of a few inconsistencies which were attributed to the cutting operation being carried out on warm plate, furnish only check data on the conclusions noted above, they are presented for what they are worth without further discussion (Fig. 51).

58814°—21——6

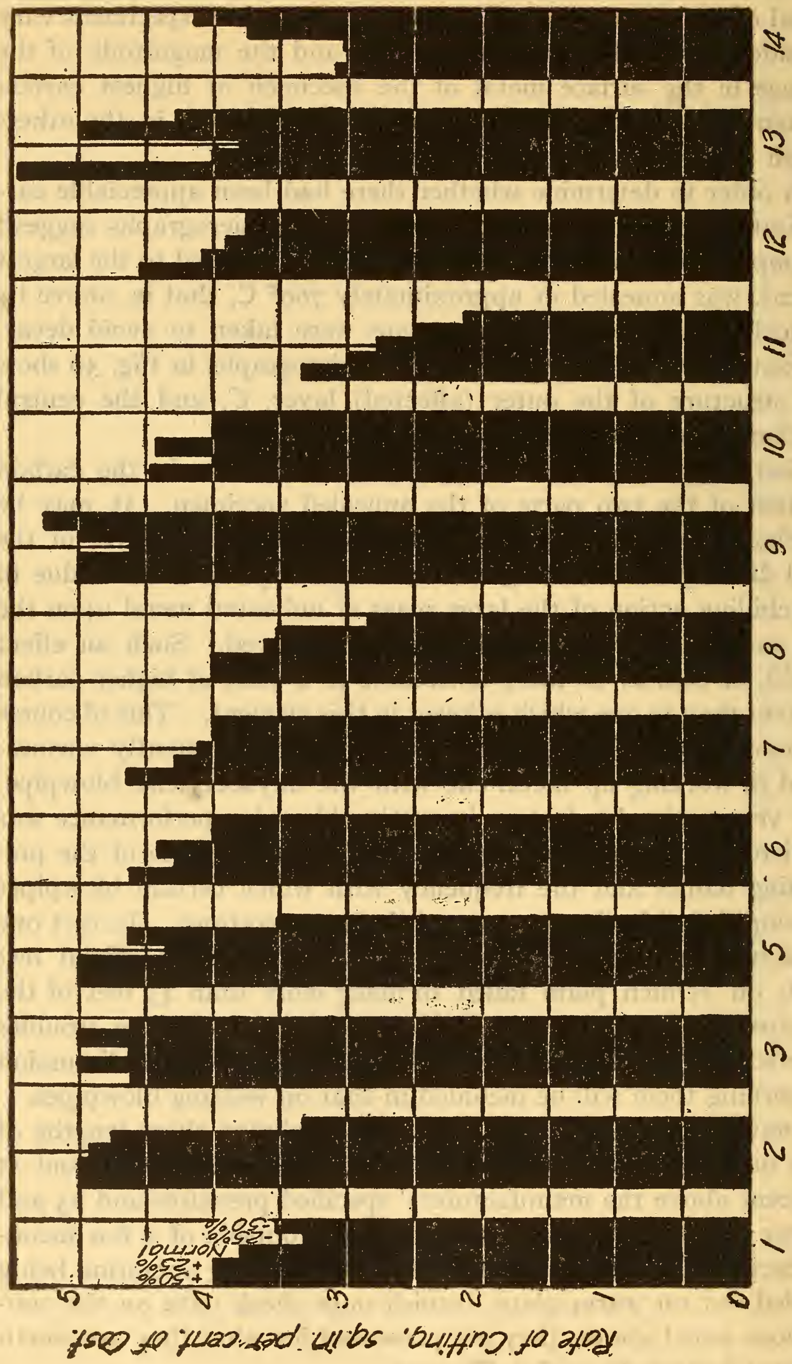


FIG. 51.—*Variations in cost of cutting 1/2-inch metal under varying pressures*

3. THE WELDING BLOWPIPE

It is universally accepted that outside of the mechanical features of design that affect weight, balance, and convenience of operation, the prime essentials of a strictly satisfactory piece of apparatus are:

1. Safety under all operating conditions.

2. Freedom from the so-called phenomenon of flash back or sustained back fire.

3. The quality of maintaining under all operating conditions a welding flame that is neither oxidizing nor carbonizing, one technically known as a "neutral flame," which in the process of combustion consumes, as nearly as possible, equal volumes of oxygen and acetylene; that is, maintains as nearly as possible the theoretical gas volume ratio of unity.

The tests of this investigation were decided upon with the idea of furnishing data that would enable blowpipe comparison relative to these essentials.

A study of the data obtained at the completion of the prescribed tests showed so many apparent inconsistencies that it was evident that there was a governing factor that was not understood, and that was, so far as test data were available, not in evidence. Irrespective of the fact that particular attention had been given to insure identical working conditions and gas pressure control, and that especial care was taken to secure exceedingly competent and unbiased operators, the results obtained from the welding tests seemed extremely unsatisfactory. Gas ratios obtained during actual welding operations were extremely high. Those obtained when the blowpipe was burning freely in air were also higher than was to be expected. In tests for flash backs there seemed to be a difference in the ease with which they could be developed in blowpipes of different manufacture, but there appeared to be no criterion that would enable one to say just why such phenomena could be caused more easily in some pieces of apparatus than in others, or why with some pieces of apparatus flash backs could be produced at times quite readily and at other times with difficulty. Finally, the general quality of the welds produced during test, although executed with the greatest care and, as shown by tensile tests, to be of a higher strength than is generally secured in most welding shops, was far from satisfactory.

It was evident that further information was essential if a satisfactory analysis of welding blowpipe performance was to be made. The greatest discrepancy from what was expected appeared to be in the high gas ratios obtained and the first attempt to answer the

problem was made by a study of gas-ratio phenomena. This seemed particularly desirable, as it has been very firmly held by almost all authorities that good welding can not be done with blowpipes having a high gas ratio.

An extensive series of supplementary gas-ratio tests was accordingly carried out. The results obtained accounted partly for the quality of the welding work secured. In some respects, though, they added increased confusion by lack of consistency.

In further study of the data secured by the prescribed tests, it was noticed that blowpipes that seemed especially susceptible to the phenomenon known as flash back were those in which the oxygen was delivered to the blowpipe at a pressure very much in excess of that at which the acetylene was delivered. It was further noticed that even among such blowpipes inconsistencies appeared. Critical examination of tip design in these later suggested a possible explanation. On this basis another series of supplementary tests was made and from the results of these data secured that clearly explain the cause of flash-back phenomena.

The logical continuance of the theory evolved for the cause of the flash-back phenomenon leads directly to the question of safety in operation and correct gas ratio and will explain, in large part, the reason for so large a proportion of oxyacetylene welds being of inferior grade.

The essential qualifications for a satisfactory welding blowpipe as enumerated above are therefore very intimately connected with the conditions governing the phenomenon of flash back. It seems desirable then to begin the discussion of the results obtained in the tests of the investigation by the critical analysis of the conditions conducive to the development of so-called flash backs in welding blowpipes.

Before taking up this discussion it will be of value to define the term "flash back" or, as it is sometimes called, "sustained back fire." It was very evident throughout the investigational tests that the representatives of the manufacturers were not in agreement as to what constitutes a flash back. To some the terms flash back and "back-firing" were synonymous, others distinguished between the blowpipe action representing these terms, and at least one other manufacturer attempted to distinguish blowpipe behavior by incorporating a term "preignition." There is therefore an apparent confusion of ideas.

For the purpose of this discussion the following definitions have been accepted as representative of blowpipe behavior under certain operating conditions.

1. Back Fire or Preignition.—Momentary retrogression of the blowpipe flame into the blowpipe tip which may relight immediately upon withdrawing the blowpipe away from the test piece or necessitate the reignition of the gases by means of a lighter. In this latter condition the flame will ignite properly without manipulation of the blowpipe handle valves.

2. Flash Back or Sustained Back Fire.—The retrogression of the burning flame back into the mixing chamber accompanied by the well-known marked hissing or squealing sound and the characteristic smoky sharp pointed flame of small volume necessitating the immediate cutting off of the gas supply by means of the blowpipe handle valves to prevent severe heating and possible destruction of the blowpipe head, and generally necessitating cooling the head before the blowpipe can be reignited.

The desirability of securing a nonflash back blowpipe has generally been considered to be due to its freedom from inconvenience and loss of time during welding operations and to its safety. Probably nothing is more detrimental to the poise of an operator and his desire to perform excellent work than an instrument that is constantly giving trouble. But the principal detriment in a blowpipe that flashes back, other than that of loss of time during welding operations, is in the possibility that a flash back may propagate itself back into the gas lines and in so doing possibly become responsible for a violent explosion with its accompanying dangers.

Blowpipe designers have devoted considerable time and money to the problem of minimizing or possibly obviating this latter danger and have devised a number of blowpipe designs that were expected to eliminate flash backs. A study of a number of letters patent indicates quite clearly that there are nearly as many theories concerning the cause of flash backs as there are patented designs. Necessarily considerable ingenuity has been shown in the attempts to accomplish the desired results. Notwithstanding the fact that some of the more recently designed blowpipes lay claim to being safe and nonflash back, still, as will be shown presently, none of those submitted to the tests of this investigation have proved free from flash back under ordinary flash-back test procedure; nor may a great many of them be considered entirely safe pieces of apparatus. The fact is that the theory back of the causes of flash back does not appear to have been fully comprehended and therefore naturally not correctly applied. Neither do any of the treatises or published articles

dealing with oxyacetylene blowpipe design or the autogenous welding process give any statements that indicate that flash-back phenomena have been understood. It is essential then that an explanation of the phenomenon be offered, especially as indicated above, as it is intimately connected with the question of sound welds. The explanation offered is based on some very old principles.

Sir Humphry Davy in the course of the researches that led to the invention of the miner's safety lamp, among other things, showed that there were certain governing principles relative to the inflammability of gaseous mixtures. He pointed out that there was a relation between the richness of the gaseous mixture and the rate of propagation of flame through it, and that such gaseous mixtures could either be enriched to the point where they ceased to be inflammable or that they could be diluted to the point where they would cease to be inflammable. It was also shown that the points where inflammability ceased were very sharply defined, but that the limits could be increased by increased temperature or pressure; and in fact that at these "critical proportion mixtures," at dilution and concentration, a very slight temperature rise will produce an inflammable mixture. It was also shown that the maximum velocity of flame propagation occurred with the gaseous mixture so proportioned that, at the completion of the combustion process, stable compounds were formed. Finally it was shown that if a gaseous mixture is ejected through a tube into the air at a velocity greater than the velocity of flame propagation for that mixture the mixture may be ignited and will burn at the exit opening of the tube without striking back into the interior of the tube. These fundamental principles were later proved to be correct in every particular by Bunsen and since then by a great number of other investigators.

The chemistry of the combustion process of a gaseous acetylene-oxygen mixture shows that the complete oxidization of one volume of acetylene requires two and one-half volumes of oxygen. Experience with the design and operation of oxyacetylene blowpipes has demonstrated the fact, however, that in reality it is only necessary to project, with the blowpipe, equal volumes of oxygen and acetylene, chemistry showing that it is a two-phased process, the second phase of which can be completed by the absorption of the remaining required oxygen from the atmosphere surrounding the flame.

The above shows that the design of the oxyacetylene welding blowpipe is based upon the fact that equal volumes of acetylene

and oxygen are to be mixed and ejected through the tube of the welding blowpipe tip at a velocity at least equal to or in excess of the velocity of flame propagation for that mixture. Under such conditions the flame will burn steadily and freely at the exit end of the tube, gathering enough oxygen from the surrounding air to complete the oxidization of the components of the acetylene gas.

A long experience has seemed to show, nevertheless, that the fulfillment of the above conditions was not sufficient in itself to maintain always the flame at the tube or tip end. It was found that if a blowpipe tip is brought too near the surface of the weld, is accidentally dipped into the molten metal of the weld, has the aperture partly blocked by flying slag, or is badly overheated, the flame will snap back into the tube, causing a so-called back fire, and may even propagate itself still farther backward until it burns at the mixing chamber, thus causing what is known as the flash-back phenomenon. It is due to the fact that this detrimental phenomenon can be so readily produced that so much energy and money have been expended in the attempt to eliminate it.

Outside of the flash back produced through the severe overheating of the head and tip of a blowpipe, it is apparent that all the other causes mentioned above seem to depend for their action upon a partial or complete blockage of the gas flow. It will be readily perceived that any sort of obstruction that checks the volume flow of the gases also increases proportionally the velocity of exit of the gaseous mixture at the tip end. Such being true, it would seem that, with the velocity of exit increased above the velocity of flame propagation, the flame could not strike back into the tube, in other words, back fire. Yet, in spite of this, back fires are caused, and it is known that with some blowpipes a back fire will immediately become a flash back, while in others it causes the extinguishing of the flame, or, if the blowpipe is withdrawn from the work, it will be blown forward again to the exit of the tip or tube. Why should some blowpipes be so much more susceptible to the development of flash back than others?

The lack of sufficient velocity of exit of the gaseous mixture has been accredited as the principal cause for flash back in some of the latest designed and most successful nonflash-back blowpipes. That there is some reason of far deeper significance than this is evident from a study of Tables 4 and 5. It is true that an obstruction to the flow will cause flash backs, but such obstruction is in reality only a contributing cause.

TABLE 4.—Summary of Tests for "Flash Back," Ordinary Conditions, Test 3

[Key: F=flash back. FOO=flash back in oxygen observation tube. FAO=flash back in acetylene observation tube. b=backfire. r=trouble in relighting. v=flame blew away and valve had to be readjusted.]

Torch No.	Tip No.[a]	Pressures used		Action of torch in tests with—			Velocity of exit	Valve wide open
		Oxygen	Acetylene	Cold steel	Fire brick	Wood		
		Lbs./in.^{2}	Lbs./in.^{2}				Ft./sec.	
[b](1)	[b](2)	[b](3)	[b](4)	[b](5)	[b](6)	[b](7)	[b](8)	[b](9)
1	6	4.00	5.00	b, r		FOO,b,r	371	Oxygen } 2 trials
	6	4.00	5.00	b, v			371	Oxygen
	8	5.75	7.00			v	380	Acetylene
2	8	8.00	8.00	b	v	v	364	Do.
	10	10.00	10.00	b			397	Oxygen
3	[c]9	6.50	8.00	b			479	Do.
	10	7.50	9.00		F	FOO, F.	427	Do.
4	35	12.00	5.00	F	F	F	366	Oxygen } 2 trials
	35	12.00	5.00	F	F	F	366	Oxygen
	36	14.00	6.00	F, r	F	F	335	Acetylene
	36	14.00	6.00	F, r	F	F	335	Acetylene } 3 trials
	36	14.00	6.00	F, r	F	F	335	Acetylene
5	[d]11	11.00	11.00	b			450	Oxygen
	[e]15	15.00	15.00	b			332	Acetylene
6	7	14.00	6.00	b	b	FAO, b.	406	Acetylene } 2 trials
	7	14.00	6.00	b	b	FAO	406	Oxygen
	9	18.00	6.00	F	F	F	375	Acetylene
	9	18.00	6.00	F	F	F	375	Acetylene } 3 trials
	9	18.00	6.00		F	FAO	375	Acetylene
7	[f]7	10.00	10.00	b	b	b	413	Oxygen
	7	12.00	12.00	b		b	462	Do.
8	6	12.00	6.00	b	b	b	495	Acetylene
	[g]7	14.00	8.00	F, b	F	F	558	Oxygen
	7	14.00	8.00	b	b	b	558	Oxygen
	7	14.00	8.00	b	b	b	558	Oxygen } 5 trials
	7	14.00	8.00	b	F		558	Oxygen
	7	14.00	8.00	b			558	Oxygen
9	[h]8	5.00	4.00	b	b	b	427	Acetylene
	9	8.00	8.00	b	b	F	391	Acetylene
	9	8.00	8.00	b		F	391	Acetylene } 4 trials
	9	8.00	8.00	b		b	391	Acetylene
	9	8.00	8.00			b	391	Acetylene
10	7	8.00	6.00	b, v	b, r	F, r	568	Acetylene } 2 trials
	7	8.00	6.00			b	568	Acetylene
	9	14.00	14.00	b		F	582	Oxygen } 2 trials
	9	14.00	14.00			b	582	Oxygen
11	5	6.00	6.00	b	b	b, r	430	Oxygen
	[i]6	15.00	6.00	b	b	b	483	Acetylene
	[j]6	15.00	6.00	b	b	b	483	Do.
12	8	4.50	4.50	b		b	370	Do.
	9	5.50	5.50	b			335	Do.
13	[k]10	21.00	1.00	F	F	F	323	Oxygen
	12	25.00	1.00	F	F	F	343	Oxygen } 2 trials
	12	25.00	1.00	F	F	F	343	Oxygen
14	[l]8	8.00	8.00	b	b	b	353	Acetylene
	[m]12	12.00	12.00	b			485	Do.

[a] Smaller size tips were used for welding ⅛-inch metal and larger size for ¾-inch metal.
[b] Column numbers.
[c] Small explosions denoting attempt at backfire in tests on brick and wood.
[d] Two backfires in 6 trials on cold steel.
[e] Too hot to hold after test on wood.
[f] Head quite hot.
[g] Half of handle too hot to hold after test on wood.
[h] Tendency to flash back not sustained with brick and wood.
[i] Monel metal tip.
[j] Copper tip.
[k] Torch head very hot.
[l] No back flash after brick was warm.
[m] Tendency to backfire with wood and brick.

TABLE 5.—Summary of Tests for Flash Back, Severe Conditions, Test 4

Torch No.	Minutes before flash back		Conditions prevailing after flash back	
	First trial	Second trial	First trial	Second trial
[a] (1)	[a] (2)	[a] (3)	[a] (4)	[a] (5)
1	1.6	1.96	Tip loose	Tip loose
2	.75	1.13		Slight leak at tip
3	.43	.75	Tip leaks in head when hot. No leak when cold	Tip leaks in head when hot. No leak when cold
4	.40	.38		
5	.50	.50		Slight leak in tip
6	.53	.90	Had to be cooled before relighting.	Tip leaked at head
7	.86	.72	Leak in top of tip, tip loose	Flashed back and relit, leaking around tip, which was loose
8	.68	.65	Tip leaked at joint	
9	.80	.68		
10	.33	.42		Small leak in bottom section of tip
11	.80	.92	Monel metal tip	
11	.38	.58	Copper tip, tip leaked around end	Copper tip, tip leaked aroun d end
12	.87	.68		
13	1.07	.85		
14	.78	.90		Handle too hot to hold

[a] Numbers in parentheses are column numbers.

Partial obstruction of the tip opening by slag, etc., or the confinement of the expanding products of combustion through bringing the tip end too near to the metal surface causes the development of a back pressure. This back pressure may be readily observed by watching a pressure gage as a lighted blowpipe tip is alternately brought in contact with or removed from a plane surface.

This back pressure has a very detrimental effect in that it chokes off the flow of the gas that is admitted under the lower pressure. Reference to Figs. 52 to 59, exhibiting results of tests in which the amount of obstruction of the exit opening was under control, shows the development of this back pressure and the restriction of the flow of the gas admitted under lower pressure.

If then the blowpipe design is such that the back pressure tends to check the oxygen supply more than the acetylene an increased richness (in acetylene) of the gaseous mixture occurs. The gaseous mixture in the blowpipe will therefore have a lower flame propagation velocity due to the fact that the increased richness is tending toward the critical proportion mixture at concentration as defined by Davy. The velocity of flame propagation is therefore decreasing while the velocity of exit has been increased by the partial closure of the orifice. There is a resulting tendency therefore for the flame to be maintained at the tip end. If under the same conditions the obstruction is sufficiently severe, the gaseous mixture within the blowpipe passes the critical proportion mix-

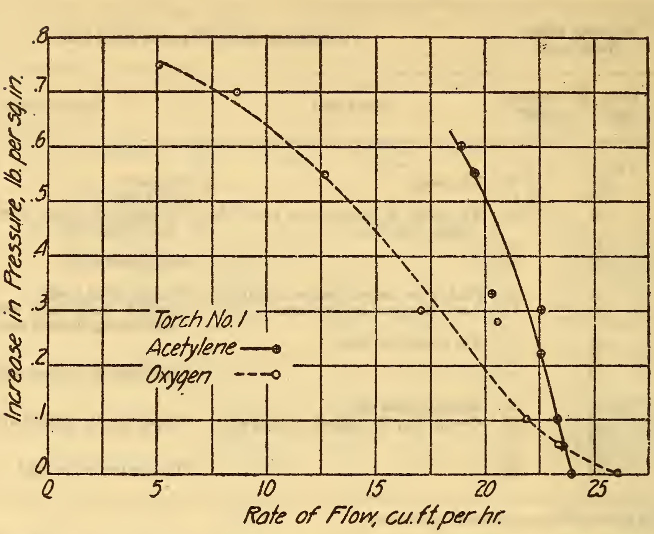


FIG. 52.—*Reduction of flow due to back pressure, torch No. 1. Test run with flame extinguished without manipulation of valves*

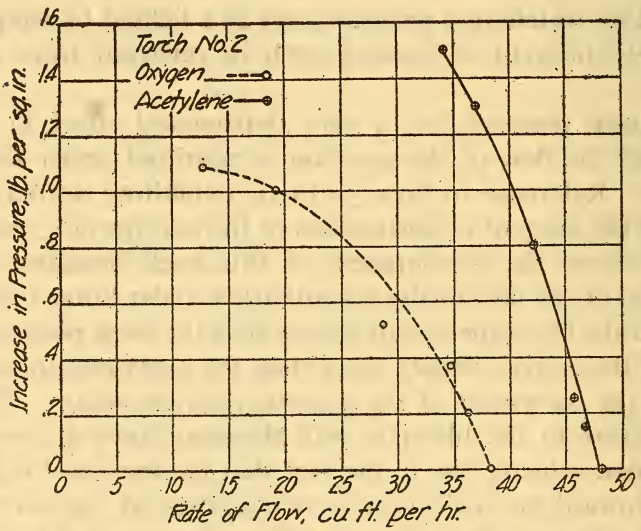


FIG. 53.—*Reduction of flow due to back pressure, torch No. 2. Test run with flame extinguished without manipulation of valves*

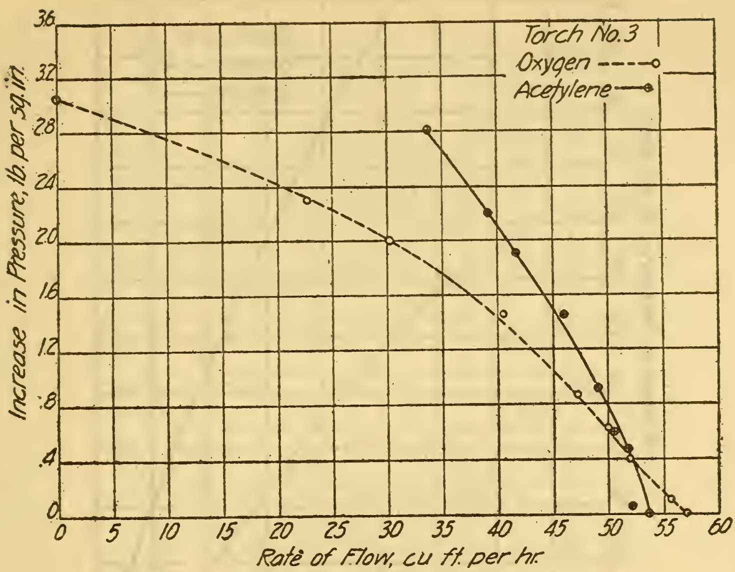


FIG. 54.—*Reduction of flow due to back pressure, torch No. 3. Test run with flame extinguished without manipulation of valves*

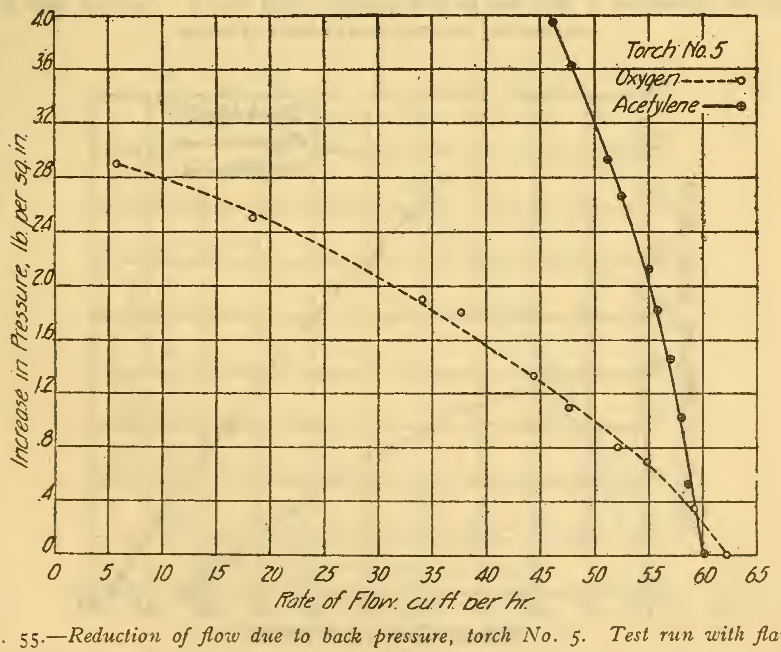


FIG. 55.—*Reduction of flow due to back pressure, torch No. 5. Test run with flame extinguished without manipulation of valves*

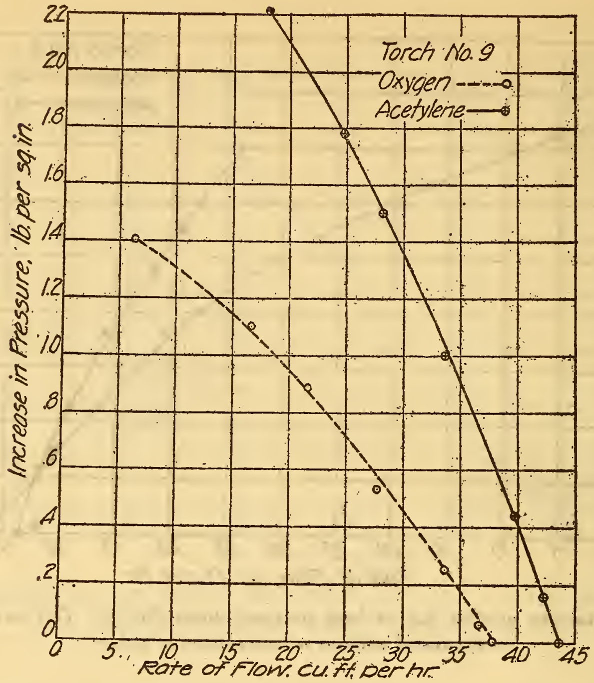


FIG. 56.—*Reduction of flow due to back pressure, torch No. 9. Test run with flame extinguished without manipulation of valves*

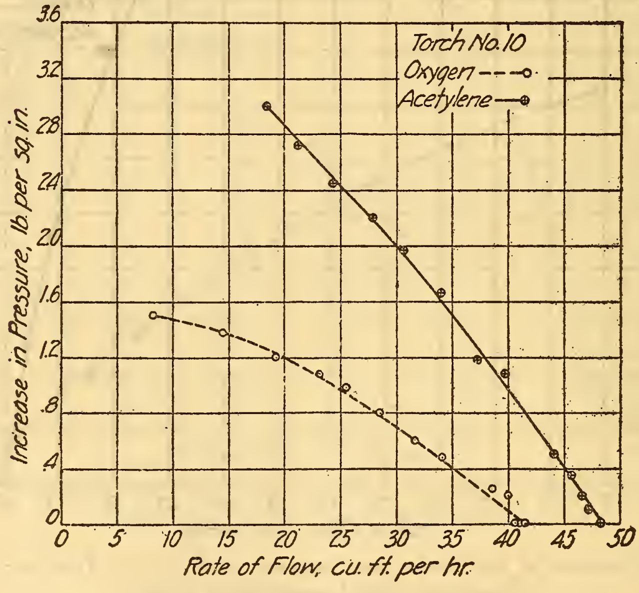


FIG. 57.—*Reduction of flow due to back pressure, torch No. 10. Test run with flame extinguished without manipulation of valves*

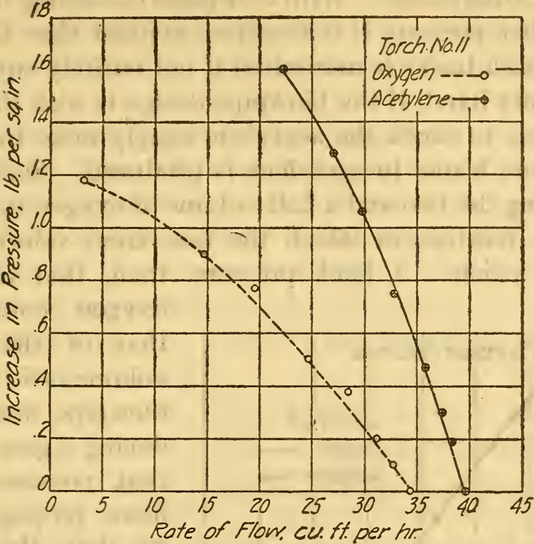


FIG. 58.—*Reduction of flow due to back pressure, torch No. 11. Test run with flame extinguished without manipulation of valves*

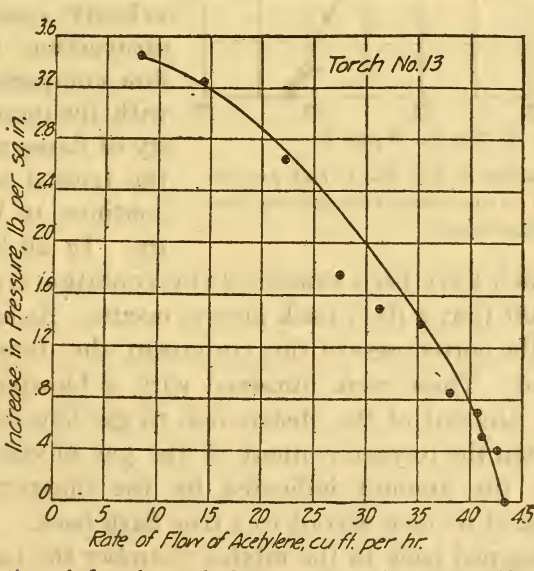


FIG. 59.—*Reduction of flow due to back pressure, torch No. 13. Test run with flame extinguished without manipulation of valves*

ture at concentration, the mixture becomes noninflammable and the flame is extinguished. With blowpipes furnishing the acetylene under a higher pressure it is therefore evident that the tendency to produce flash backs is minimized if not entirely suppressed.

On the other hand, if the blowpipe design is such that the back pressure tends to check the acetylene supply more than the oxygen, a mixture leaner in acetylene is produced. Such a mixture is approaching the two and a half volume of oxygen to one volume of acetylene mixture at which the maximum velocity of flame propagation exists. A back pressure, then, that increases the oxygen content above that of the one-to-one volume ratio furnished in blowpipe design is producing a gaseous mixture that possesses a higher flame propagation velocity than that possessed by the one-to-one mixture.

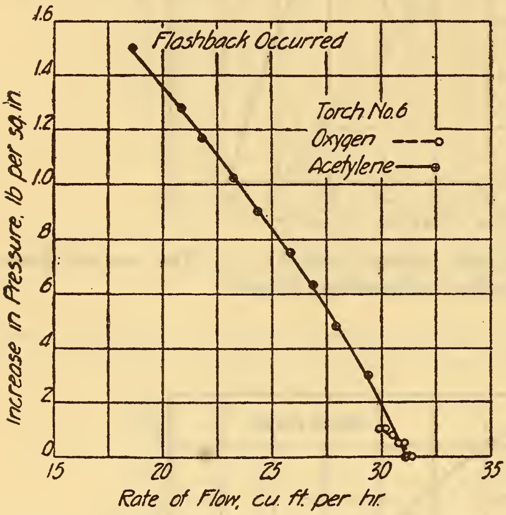


FIG. 60.—*Reduction of flow due to back pressure, torch No. 6. Test run without extinguishing flame or manipulating valves*

If the increased exit velocity caused by the obstruction to the gas flow compares favorably with the increased velocity of flame propagation, the ignited mixture will continue to burn at the tip. In all blowpipes of this type which have been examined this condition is not fulfilled, with the result that a flash back always occurs. As experimental evidence of the correctness of this statement the data of Fig. 60 are presented. These were obtained with a blowpipe mounted so that the amount of the obstruction to gas flow could be controlled. When the oxygen content of the gas mixture had been increased to the amount indicated by the diagram the flame snapped back of its own accord to a true flash back.

Having snapped back to the mixing chamber the back pressure will be destroyed and the flow becoming normal again, the flame burns there in the volumes permitted by the blowpipe construction with insufficient oxygen to cause complete oxidization and the acetylene gas is broken up into its components one of which

unites with the available oxygen to form water vapor, leaving carbon deposited on the walls of the tip tube and mixing chamber. This explains not only the heavy carbon deposit that is always left as the result of a flash back but the reason why it is relatively so moist.

It is of course possible that if the oxygen content of the gaseous mixture could be increased beyond the proportions for maximum velocity of flame propagation, that is, beyond the two and a half to one volume ratio, the velocity of flame propagation might be reduced sufficiently to compare favorably with the exit velocity. In the light of the above, however, it is evident that this condition can not be produced, nor would it be desirable, as the flame would be extremely oxidizing.

At how great a disadvantage the high pressure oxygen blowpipe designs are as compared with those operating with acetylene delivered at excess pressure is very apparent from another consideration. Eitner [4] has shown that the lower inflammable limit by percentage volume of combustible gas in a mixture of acetylene and air is about 3.35 per cent, and that the upper limit is about 52.3 per cent. There is no doubt that with a more active gas, such as oxygen, the lower limit will be at least the same and possibly the upper limit will be found to be slightly raised. Bearing in mind that normally a 50 per cent mixture is being passed to the mixing chamber, it is readily seen that the critical proportion mixture at concentration is reached very soon, while the critical proportion mixture at dilution is not reached until almost the entire combustible gas supply has been shut off.

It has been known for some time that an operator could extinguish a flash back in a high-pressure blowpipe by suddenly increasing the oxygen pressure or by crimping the acetylene supply line. The reasons are now very apparent. In the former case the oxygen volume ratio is greatly increased by the accelerated checking of the acetylene supply until the volume ratio is diluted beyond the maximum explosive mixture, the flame propagation velocity is thereby reduced, and at the same time the increased pressure of the oxygen expels the mixture at increased velocity. The flame may therefore be pushed to the outlet opening of the tip. In the latter case, crimping the hose line, the combustible gas is shut off and the flame may be pushed forward as above or may go out from the gas mixture having reached the critical proportion

[4] L. A. Groth, Welding and Cutting Materials by Aid of Gases or Electricity, Archibald Constable & Co. (Ltd.), London, p. 251; 1909. See also G. A. Burrell and G. G. Oberfell, the Explosibility of Acetylene, Bureau of Mines Technologic Paper No. 112, p. 5; 1915.

mixture at dilution; but in this case, on account of the low percentage mixture at which this occurs, it may as well be caused through the entire combustible gas supply having been cut off.

Having explained the conditions necessary for, and the action of flash-back phenomena, it is of interest to determine why some blowpipes flash back so much more readily than others of similar design; as, for example, those in which the oxygen pressure is higher than that of the acetylene. The rapidity of development of the condition for producing a flash back depends entirely upon the rapidity with which the back pressure is set up. That there is a difference in the rate at which the back pressure is developed is evident from an inspection of Figs. 52 to 59. The data of these tests show that those blowpipes which were more susceptible to flash back from obstruction of gas flow were those in which the back pressure most rapidly diminishes the acetylene flow. A blowpipe operating on the injector principle or one in which the oxygen pressure is very much in excess of the acetylene pressure will therefore be far more susceptible to flash-back phenomena.

An investigation of the actual pressures specified by the manufacturers, as well as a study of certain letters patent, indicates that a few of them at least, in their experimental work, have become cognizant of the effect a gas mixture rare in acetylene has upon the development of a flash back. To overcome flash-back troubles, several of the recent designs are based upon furnishing acetylene under a higher pressure, spoken of in the letters patent as higher velocity, than that used for the oxygen. Reference to Tables 4 and 5 shows that flash backs can be caused in apparatus of that type. The question may rightly be asked as to why flash backs can then be developed in such blowpipes.

A critical study of the design of the blowpipe tips shows further that the way in which one stream of gas is admitted into another has a decided effect upon conditions resulting from the development of a back pressure.

A back pressure caused by tube obstruction pushes back into the tube in the most direct line (Fig. 61). An acetylene gas passage entering the oxygen tube at right angles has its gas flow cut off very quickly, especially when the oxygen pressure is much higher than the acetylene pressure and the point of admission of the oxygen is, as it is in most of the tip designs, beyond the point of admission of the acetylene.

In this respect a gas passage entering the oxygen passage at a sharper angle is more advantageous, but, under certain conditions, this construction may not produce results that are any

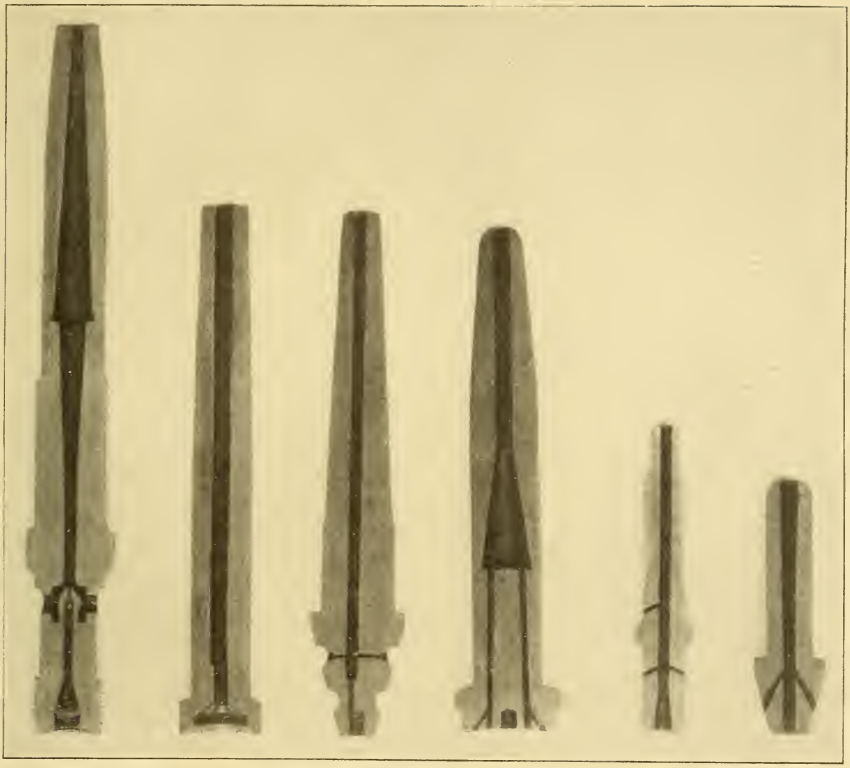


FIG. 61.—*Views of cross sections of tips*

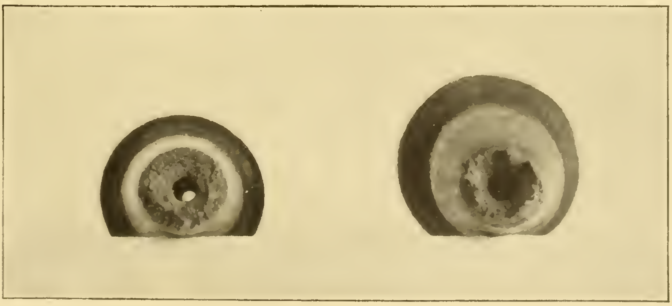


FIG. 62.—*Tips after a flash back*

more desirable. If the velocity of the oxygen jet is relatively high and the acetylene gas ports are placed at an angle to the tube of the oxygen jet, an aspirator or injector action is developed relative to the acetylene. The higher the velocity of the oxygen the greater is the aspirating effect on the gas tube. This aspirating effect is in reality an attempt to produce a partial vacuum within the acetylene tube. If, then, while operating under such conditions a sudden obstruction of the exit passage occurs with its accompanying back pressure development, the sudden release of the aspirating action causes a collapse of the partial vacuum and the gas passage tube is therefore momentarily choked or at least throttled by the infiltration of oxygen. This action instantly produces the leaner mixture and conditions necessary for the development of a flash back.

But there are also two other fundamental physical laws which apparently have not been given proper consideration in the designs of blowpipes, and which will probably account in a far larger measure for the development of flash-back conditions. These laws refer to:

1. The variation of velocity of a fluid in a pipe of varying size.
2. The diminution of pressure in a throat.

The first law recognizes the fact that the mass discharge of a fluid at all sections is a constant; hence for a pipe of varying size, as shown, the following condition holds when the friction loss of pressure is neglected:

If $a > a'$, then $av < a'v'$, where
a and a' = areas of gas passage,
v and v' = velocities of gas.

This indicates that at various points along a tube the velocities of the fluid increase as the section areas decrease.

The second law is based on the fact that, neglecting friction and eddy losses, at any two sections of such a tube the total energy per unit mass will be equal; that is, an increased velocity produces a decreased pressure.[5]

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[5] The relation for a gas is given by the equation

$$v'^2 - v^2 = 2TC_p\left[1-\left[\frac{p'}{p}\right]^{\frac{C_p-C_v}{C_v}}\right], \text{ in which}$$

p and p' = pressure;
v and v' = velocities;
d = density;
T = absolute temperature;
C_p = specific heat at constant pressure;
C_v = specific heat at constant volume.

The decrease of pressure with increase of velocity is perhaps more clearly shown by the approximate formula

$$p+\frac{1}{2}dv^2 = p'+\frac{1}{2}dv'^2,$$

which neglects the expansion of the gas.

From these two laws it is evident that if the area of a tube is contracted with the idea of securing increased velocity the pressure in the contracted area is reduced.

Reference to Fig. 61 shows that in practically all designs the contracted throat is used in the acetylene passages. It will be readily realized then that in even those blowpipes which are supposed to operate with acetylene delivered at excess pressure there exists in the fundamentals of their design an inherent tendency for the choking off of the acetylene supply and the development of the leaner flash-back mixture at the first indication of back pressure.

The inherent defects in the present designs show plainly then why it is also possible to produce a flash back almost at will in the blowpipes that are designed on the excess acetylene pressure basis. It is evident, therefore, that none of the blowpipes designed for use with one gas delivered at a higher pressure than that used for the other are really free from flash-back troubles caused by obstructions to the gas flow.

There is another important consideration to be discussed relative to blowpipes using one gas at higher pressure, and that is their safety during operation. The foregoing discussion shows that an obstruction to the gas flow issuing from the tip sets up a decided and effective back pressure and that the back pressure thus set up will be sufficient not only to check the flow of the gas admitted under the lower pressure, but also actually to push it back into its supply tube and line. The return of one gas into the supply line of the other instantly forms an explosive gas mixture back of the mixing chamber. Reference to the exceedingly low limit of the critical mixture at dilution as indicated by Eitner's investigations shows how rapidly a dangerous mixture can be formed by a blowpipe using acetylene under excess pressure. A blowpipe using the oxygen under the excess pressure is about equally as dangerous. It is simply a question of the time interval the back pressure has available to accomplish its results.

The degree of danger from this cause is greater, the greater the difference in pressure. A blowpipe operating with one gas at a pressure greatly in excess of the other can force a return mixture just so much more quickly than a blowpipe operating with less difference in pressures. Also with one pressure greatly in excess of another a larger amount of explosive mixture will be formed back in the tube or line, as the distance the explosive mixture will be forced back depends upon how quickly the equalizing

element, the pressure developed by the compression of the gas in the tube, overcomes the effect of the back pressure.

In connection with this phenomenon of the creation of explosive mixtures in tubes and lines due to back pressure, it seems desirable at this time to call attention to the decidedly dangerous influence leaks in the supply lines can have in cases where a dangerous mixture is being forced backward in one tube.

With the knowledge that the back pressure set up by the obstruction of gas flow from a tip can return a dangerous explosive mixture into the tubes and supply lines, and further with the realization, now apparent at least, that none of the unequal pressure blowpipes are free from the possibility of the development of a flash back, it can be readily seen that no blowpipe on the market to-day that operates under unequal or unbalanced pressures can with assurity be declared absolutely safe. This is especially true as it has not as yet been established how small an opening will have to be before it will cease to propagate a flame through an explosive mixture of oxygen and acetylene. It is known, though, from the investigation carried on to determine the feasibility of acetylene lamps for mine use, that the opening is very small. That the return of such explosive mixtures can be caused is evidenced by reference to Table 4.

Recognizing the dangers coincident with blowpipes operated under dissimilar pressures, some manufacturers have attempted to minimize the return of dangerous gas mixtures by incorporating check valves in the blowpipe construction. While such desires are commendable they are in their method of fulfilment of doubtful value in that there is no assurance that the valves will always be operative. Failure, or loss of life in springs, or pieces of dirt or scale, or corrosion of a stem or seat may readily cause a check valve to fail to function. Its utility then is very questionable.

Other manufacturers have sought safety in action by attempting a design based on delivering the gases under equal pressure. Possibly also they have realized to some extent the effects of excess oxygen or acetylene on the development of flash-back phenomena. A very careful study of their letters patent shows, however, that they have not completely understood the phenomenon, its cause and effects, and the methods necessary for its suppression. It is therefore not surprising that not one of the so-called equal pressure blowpipes proves actually to be such. The data of Table 4 show this beyond a doubt. They are therefore at times subject to the same flash-back difficulties and the same lack of safety in

operation, their differences being only a question of relative degree and subject to the same principles mentioned above.

In mentioning above the things that seemed to be responsible for the flash back, specific reference was made to overheating of the tip and head. All blowpipes can be made to flash back from such a cause. How quickly they will do so seems to depend entirely on their design. It is certain that water-cooled heads can assist in restraining such flash backs. It is also apparent that a tip and head made of metal of high thermal conductivity, pure copper, for example, is beneficial. In fact, any construction that tends to maintain a cool gas flow seems to be helpful, and it is probable that in that fact lies the explanation for flash backs caused by overheating of blowpipe parts.

It will be recalled that Davy's experiments showed that the critical mixture proportions were affected by changes in temperature, that a slight increase in temperature may make what is normally a noninflammable mixture inflammable. It is known also that the velocity of propagation of flame is increased with increases in temperature. It is evident, then, that under the influence of a high temperature there is an increasing tendency for even a blowpipe designed for operation with excess acetylene to flash back on the development of back pressure.

The real cause for flash backs developed under the influence of high temperature, where back pressure does not necessarily exist, is probably due to the sudden heating to the ignition point of a large volume of gaseous mixture. The tip and head become extremely hot for their entire length and subject a relatively large volume of gas mixture to the effects of the high temperature. The result is naturally a detonation. The suddenness and violence with which such flash backs occur and their destructive effects on the tips ends, as shown in Figs. 62 and 63, are evidence that the burning gaseous mixture has been subjected in reality to a detonation.

The difference in action that takes place in the two forms of flash back, namely, those caused by back pressures and those caused by detonation of the gaseous mixture, can probably be best illustrated by calling to mind the familiar facts concerning gun cotton, a material that, lying loosely and open to the air, will burn harmlessly if ignited by flame, becomes a most violent explosive if fired by a percussive detonator. It is a question of the rapidity with which a large volume of the mixture is ignited.

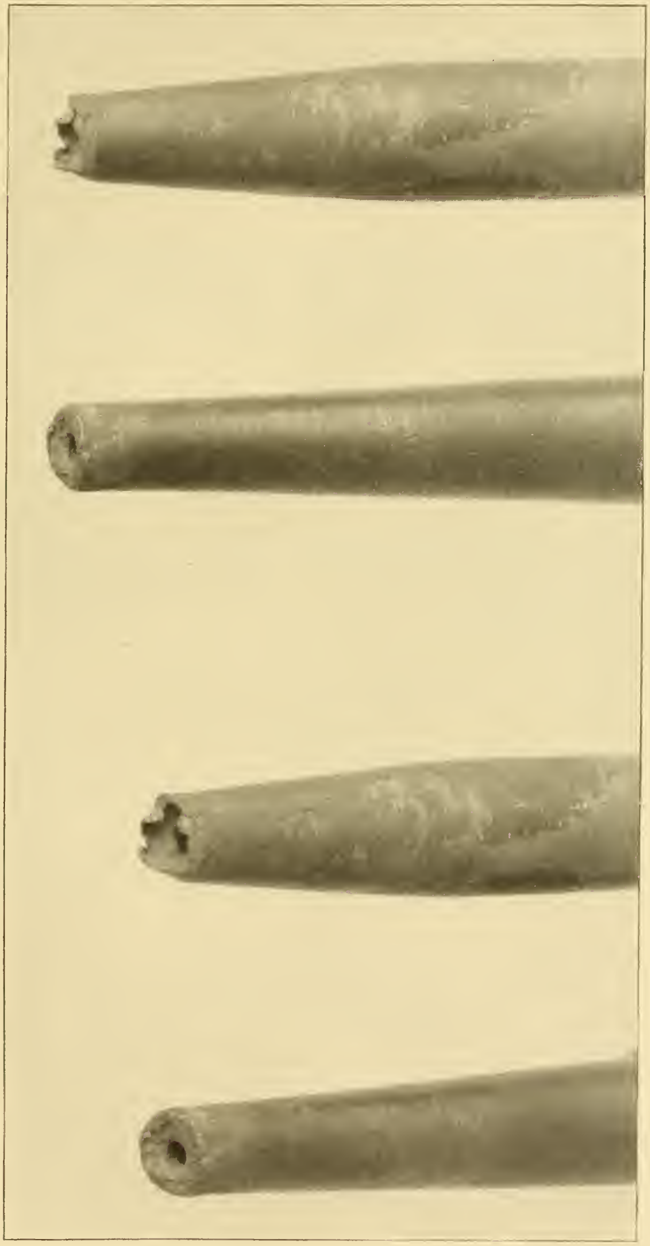

FIG. 63.—*Tips after a flash back*

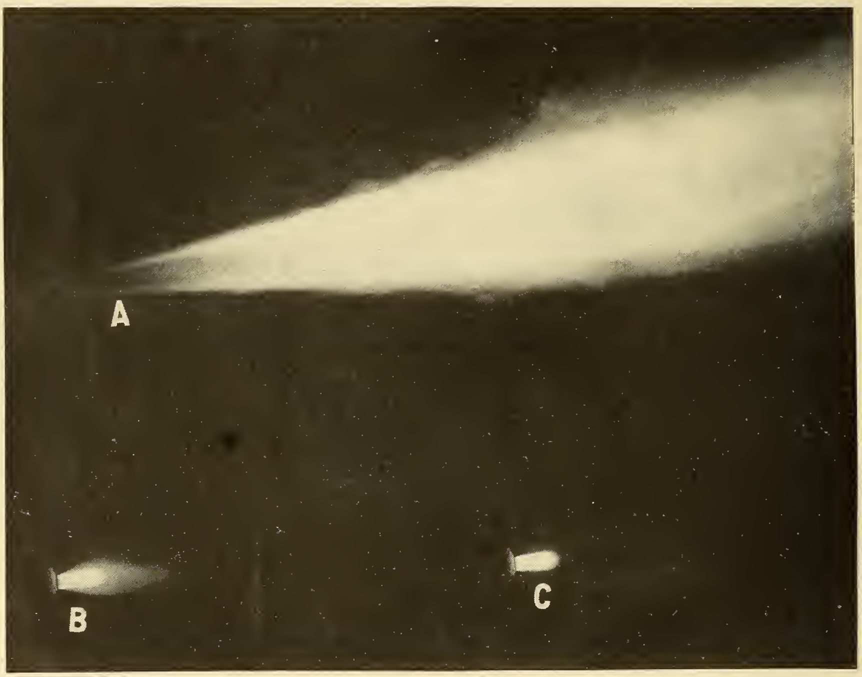

Fig. 64.—*Oxyacetylene flames*

A.—Acetylene flame, no oxygen
B.—Slight excess of acetylene
C.—Neutral flame

If, then, the sudden firing of a relatively large volume of a gaseous mixture produces a detonation, it is quite evident that the rate of flame propagation is exceedingly high. For an oxygen-hydrogen mixture it has been reported as approximately 9315 feet per second; for a carbonic-oxide mixture, a relatively slow and inert combination, at about 3575 feet per second.[6] Figures for acetylene do not seem to be available, but it is certain that they will be nearly as high as those for hydrogen.

The futility of attempting to prevent flash backs from this cause by ejecting the mixture at a high velocity is very apparent Knowledge, however, of the cause of the action indicates that anything that tends to keep the gaseous mixture cool tends to hinder the development of such flash backs.

Having discovered the causes of the development of the so-called flash-back phenomenon, and shown that the safety of a blowpipe is dependent upon the causes back of this same phenomenon, it is next in order to inquire as to what possible effect the causes of flash backs may have upon the gas ratio; that is, upon the economy of operation and upon the process of autogenous welding.

The questions are hardly proposed before their answers are apparent. It cannot be expected that a blowpipe whose gaseous volume mixture is constantly changing from the one-to-one volume ratio to an excess carbon (acetylene) content or an excess oxygen content can maintain a constant gas ratio or a truly neutral flame. If this is so, it is hopeless to expect such blowpipes to be capable of producing unoxidized or uncarbonized welds.

The controversy on the causes for unsound welds has of course been two sided. It has been said that even experienced welders excuse the shortcomings of their work by claiming that the blowpipe or the welding rod was not good. But generally up to this time the condemnation has been placed principally upon the welder and there is no doubt in certain cases rightly so.

In certain quarters the oxyacetylene weld has been severely criticized. As a result of this criticism it has been suggested that all welders should receive special training, that the quality of their work be constantly checked by tests, and that they be licensed. Extensive metallurgical studies of welds, and attempts to find nonoxidizing welding rods have also been made. All these are good and useful expedients, but if in the first place the operator is not furnished with a blowpipe that has been designed

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[6] D. Clerk, The Gas, Petrol, and Oil Engine, p. 116.

with a correct interpretation and application of fundamental physical laws, it can not be expected that sound welds will be forthcoming, no matter what other expedients are employed to increase the efficiency of the weld.

The oscillatory motion given to the blowpipe in the process of welding and the trembling of the operator's hand, by causing a constantly varying back pressure as the blowpipe tip approaches or recedes from the surface of the weld insures a constantly fluctuating gaseous mixture with a predominating tendency, as indicated above, toward an oxidizing flame.

In the more careful welding operations very great pains are usually taken to burn out oxide or slag pockets, etc., with the result that the tip end is forced down into a confined space. Even with such care welds are found to be oxidized. The bottom of the V of a weld is almost always oxidized, while the upper portion may show more or less of the clean cast metal. It has been known for years that a shaky-handed welder could not make sound welds. It has also been known that certain blowpipes, as regards flash back, were particularly susceptible to the nearness with which the blowpipe tip approached the welding surface. Further, some at least have known that after placing an ignited and properly adjusted blowpipe flat on a surface and then gradually raising the head, keeping the tip upon the surface meanwhile, the blowpipe would flash back after the head had been elevated to a certain angle. These are some of the facts that indicated that there was being developed at such times the detrimental back pressures.

All the data available as a result of the investigation bear out the logical conclusions of the above theory—the high gas ratios during welding, the difference in gas ratios when identical tests are performed by different operators, the lower gas ratios when a blowpipe burns freely in air (see Table 6), the fluctuations in volume flows as determined by flow-meter readings taken every few minutes with gas pressures maintained within a few hundredths of a pound per square inch throughout the entire test period. (See Fig. 21.) Most convincing of all is the wide variation in the physical properties of the welds made during the investigation, a group of welds that probably was made with greater care than has ever been bestowed upon any other such set. (See Figs. 65 to 71.)

All past experience, including the experience gained during these tests, points to but one convincing conclusion, namely, that a blowpipe designed to be absolutely free from flash back

caused by any form of obstruction, under all working conditions, will also be the eminently safe blowpipe and the blowpipe that will with ordinary care produce sound welds. Such a blowpipe will be one so designed that under all conditions of operation, even to complete blocking of the gas exit at the tip end, there will be maintained a one-to-one volume delivery of each gas at identical pressures. No oxyacetylene blowpipe on the market to-day fulfills these fundamental conditions.

A few other points are of interest in connection with the welding blowpipe investigation. It was mentioned above that one of the most noticeable outstanding features which was the first to be investigated in the attempt to solve the apparent discrepancies in welding blowpipe data was the high gas ratio obtained during welding operations. Attention has also been called to the fact that such ratios were lower when the blowpipe burned freely in air. The reason for this is of course now apparent. But it will be of interest to note that even such values were relatively high, and this notwithstanding the further fact that in a majority of gas-ratio tests the neutral flame was set in the presence of and met the approval of experienced blowpipe operators, representatives of the manufacturers. Consideration of these facts led to the belief that what is called the neutral flame is more or less masked by the operator's personal equation, that is, what he considers a neutral flame to be. Further, continued experience indicated that when the gases were issuing at a high velocity the extreme ragged edge of the inner cone seemed to interfere with the determination of the neutral flame. It became apparent, then, that the general tendency was toward setting an oxidizing flame. This was strengthened by the knowledge that all treatises and books of instruction that were available describe the neutral flame as having been secured when the intensely white flame or inner cone is "sharp in outline—symmetrical and smooth." (Fig. 64.) The trouble with this statement lies in the emphasis given to the words "sharp" and "smooth." In adjusting the burning gases to produce a neutral flame it seems to have become an ingrained action upon the part of the operator to cut the acetylene gas flow back until the entire inner cone is "sharp" and "smooth," with the result, as exhibited by the gas-ratio tests of this investigation, that the flame has actually been made quite oxidizing.

Having come to this conclusion, the idea of examining the flame spectroscopically presented itself, and for this purpose,

because of its convenience, a replica diffraction grating was used. The use of this method suggested itself, as it was recognized that in a carbonizing flame there must exist unburned incandescent solid carbon particles which would superimpose their blurred continuous spectra over the line spectra of the flame. Such proved to be the case, and it was found, as anticipated, that probably too much attention has been paid in the past to setting the inner cone to too sharp a contour, especially on the extreme end. The results of a series of gas-ratio tests run with the use of the gratings are shown also in Table 6, and it will be noticed that they show very marked changes in values and much greater uniformity.

This table shows that practically any of the present blowpipes can be made to produce a neutral flame and burn equal volumes of oxygen and acetylene if the flame can burn undisturbed in the air. But, as stated above, none of them can maintain such a flame during the welding process.

TABLE 6.—Summary of Tests for Gas Ratios

Torch No.	Gas ratios for test No.—						
	1-a	1-b	2	5-a-1	5-b	With gratings	
						5-a-1	5-b
[a](1)	[a](2)	[a](3)	[a](4)	[a](5)	[a](6)	[a](7)	[a](8)
1	1.13 [b] (1.11)	1.16 (1.15)	1.14 (1.14)	1.19 (1.18)	1.08 (1.04)	1.04 (1.05)	1.01 (.981)
2	1.12 (1.11)	1.07 (1.06)	1.08 (1.06)	1.04 (1.04)	1.06 (1.04)	1.04 (1.02)	.992 (.996)
3	1.21 (1.18)	1.26 (1.23)	1.13 (1.19)	1.10 (1.07)	1.07 (1.09)	1.01 (1.01)	1.04 (1.09)
4	1.13 (1.13)	1.09 (1.09)	1.41 (1.16)	1.14 (1.15)	1.29 (1.10)	... ...	... ...
5	1.07 (1.05)	1.05 (1.04)	1.03 (1.13)	1.02 (1.02)	1.04 (1.10)	1.01 (1.01)	.999 (1.03)
6	1.10 (1.10)	1.11 (1.11)	1.14 (1.15)	1.12 (1.12)	1.17 (1.16)	1.06 (1.03)	1.08 (1.07)
7	1.07 (1.04)	1.05 (1.03)	1.03 (1.02)	1.04 (1.01)	1.07 (1.03)	1.05 (1.01)	1.02 (.994)
8	1.13 (1.12)	1.12 (1.12)	1.18 (1.16)	1.27 (1.28)	1.43 (1.38)	1.05 (1.03)	1.01 (.986)
9	1.15 (1.18)	1.18 (1.24)	1.19 (1.17)	1.14 (1.14)	1.14 (1.15)	1.43 (1.39)	1.19 (1.15)
10	1.12 (1.11)	1.15 (1.13)	1.19 (1.06)	1.10 (1.09)	1.04 (1.05)	1.03 (.989)	1.01 (.992)
11	1.19 (1.19)	1.20 (1.21)	1.26 (1.23)	1.27 (1.28)	1.09 (1.08)	1.21 (1.19)	1.04 (1.05)
12	1.21 (1.17)	1.21 (1.20)	1.13 (1.11)	1.02 (1.01)	1.04 (1.02)	1.02 (.998)	1.02 (.979)
13	1.02 (1.04)	1.13 (1.12)	1.09 (1.09)	1.09 (1.08)	1.07 (1.06)	1.02 (1.01)	1.00 (1.00)
14	1.07 (1.06)	1.09 (1.08)	1.08 (1.07)	1.08 (1.08)	1.10 (1.10)	.999 (.992)	.956 (.964)

[a] Column numbers.
[b] Values in parentheses are computed from flow-meter data.

TABLE 7.—Summary of Results of Tensile and Bend Tests of the Oxyacetylene Welds Made in Tests 1-a, 1-b, 1-c, 1-d, and 2

Torch No.	Ultimate tensile strength and angle of bend, test No.—									
	1-a		1-b		1-c		1-d		2	
	U. t. s.[a]	Inc. ∠[b]	U. t. s.	Inc. ∠	U. t. s.	Inc. ∠	U. t. s.	Inc. ∠	U. t. s.	Inc. ∠
[c](1)	[c](2)	[c](3)	[c](4)	[c](5)	[c](6)	[c](7)	[c](8)	[c](9)	[c](10)	[c](11)
1..........	39.3	116	44.4	115	33.1	44	42.1	77	43.6	51
	44.9	121	47.4	95	....	....	....	....	....	....
2..........	41.2	29	39.4	39	41.2	67	45.8	58	43.7	69
	44.1	56	43.9	67	....	....	....	....	....	....
3..........	31.9	50	27.9	28	[d]43.0	[d]94	35.3	37	33.2	30
	32.1	36	35.9	20	[e]38.9	[e]62	....	....	....	....
4..........	36.2	62	41.4	95	40.6	61	39.0	107	53.5	117
	43.0	41	36.7	73	....	....	....	....	....	....
5..........	43.0	72	31.1	63	43.6	34	32.1	18	33.0	52
	46.3	25	37.7	63	[e]42.9	[e]42	....	....	....	....
6..........	40.6	72	45.8	59	34.4	16	44.3	56	48.6	44
	43.7	69	42.3	65	....	....	....	....	....	....
7..........	44.2	33	37.3	56	36.1	73	36.3	53	48.2	49
	46.0	77	40.8	65	....	....	....	....	....	....
8..........	43.4	43	39.8	64	32.9	20	39.5	80	41.4	74
	43.8	70	42.6	60	....	....	....	....	....	....
9..........	....	....	34.9	38	42.0	67	44.1	71	44.9	57
	46.5	62	45.2	39	....	....	....	....	....	....
10.........	41.9	54	35.1	26	[d]47.7	[d]89	45.6	72	39.4	23
	43.1	59	39.6	51	....	....	....	....	....	....
11.........	43.8	54	38.7	66	37.9	36	38.4	96	45.1	39
	27.0	51	29.2	57	32.8	38	....	....	....	....
12.........	40.4	43	39.0	54	42.3	60	49.4	94	45.8	62
	40.2	32	39.5	56	....	....	....	....	....	....
13.........	39.3	51	31.0	83	40.1	61	34.4	82	48.3	58
	52.1	61	41.6	24	....	....	....	....	....	....
14.........	40.4	63	45.6	107	39.4	52	42.4	65	38.1	38
	41.0	49	46.5	66	....	....	....	....	....	....
Average: First plate..	40.4	57	38.0	64	38.6	49	40.6	69	43.3	54
Second plate..	42.4	58	40.6	57	32.8	38	....	....	....	....
General average[f]	41.4	57	39.3	60	35.7	44	40.6	69	43.3	54

Average ultimate tensile strength of all welded ½-inch plates.................................. 39.2 lbs./in.²
Average ultimate tensile strength of unwelded ½-inch plates.................................. 54.9 lbs./in.²
Efficiency of welds in ½-inch plate.. 71.4 per cent.
Tests numbered 1 were welds made with ½-inch plates; test 2 was made with ¾-inch plate.

[a] U. t. s.=ultimate tensile strength in thousands of pounds per square inch.
[b] Inc. ∠=included angle of bend, cold-bend test. Bottom of V in compression. Pin diameter equal to thickness of metal. Included angle for unwelded plate=180°.
[c] Numbers in parentheses are column numbers.
[d] Weld made at −50 per cent pressure instead of +50 per cent pressure.
[e] Weld made at normal pressure instead of +50 per cent pressure.
[f] Welds referred to in footnotes [d] and [e] are not included in the general average.

Referring again to the strengths of the welds executed during these tests (see Table 7), it will be seen that the second plate welded during each test invariably showed higher strengths. It will be remembered that to counteract the effects of expansion the 2-foot test welds were made by welding two 1-foot lengths of plate. These plates were supported on a heavy iron casting that contained a channel throughout its length parallel to and directly under the line of welds. This channel caused the flame of the blowpipe to

return under the plates being welded and thus preheated to some extent the second plate. Further, it caused a decided heating of the near end of the base casting. The explanation for the higher strength shown by the second plates probably lies in the more uniform preheating of the second plate and the greater annealing effect produced by the heated base casting, the latter causing a release of the tensile strains resulting from the contraction of the metal along the line of the weld.

The average strengths and average included angle of bend are given in the above-mentioned table (Table 7) for what they are worth. It is very probable in the light of present knowledge of the requirements of blowpipe design, that some new ideas will be forthcoming concerning the average strength of oxyacetylene welds. Finally in Figs. 65 to 71 are exhibited microphotographs showing the effect upon the grain structure of the material, in this case mild steel, of the autogenous welding process, effects not necessarily detrimental when properly performed, but, as exhibited by the microphotographs, instructive.

VII. SUMMARY

In conclusion, the results of this investigation would seem to warrant the following statements.

For the Cutting Blowpipes.—1. There is to-day no generally accepted theory for proportioning, for the cutting of metal of various thicknesses, the volume and velocity of the issuing cutting jet, with the result that none of the apparatus submitted to test proved economical for all thicknesses.

2. There is for any thickness of metal cut a limiting velocity of exit of the cutting jet, at which complete utilization of the oxygen takes place and a limiting value for the amount of oxygen required to produce a cut.

3. That an increase in acetylene consumption, in oxygen consumption, or in the velocity of exit of the cutting jet beyond the limiting values does not produce increased efficiency in commensurate ratio.

4. That a large majority of the blowpipes tested were equipped with excessive preheating flames for the thickness of metal the tip is specified for, and that such excessive sized flames are disadvantageous both from the standpoint of economy of operation and quality of work performed.

5. That considerable improvement in economy of operation seems possible in cutting material of 2-inch thickness, and that

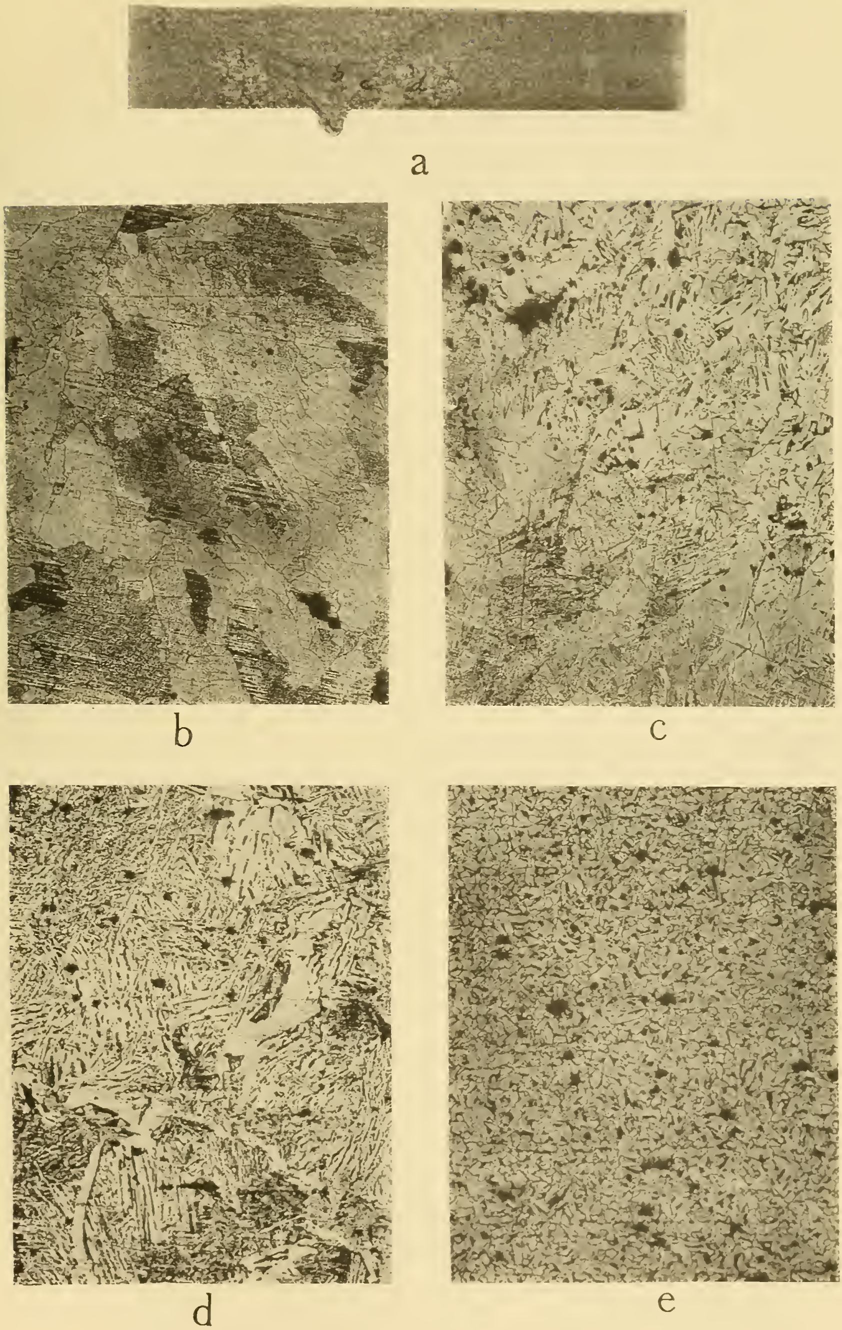

Fig. 65.—*Microphotographs (× 50) of weld No. 51*

a.—Welded plate, natural size. Location of microphotographs indicated
b.—Weld metal
c.—Junction of weld and plate
d.—Overheated plate metal near weld
e.—Unaltered plate metal

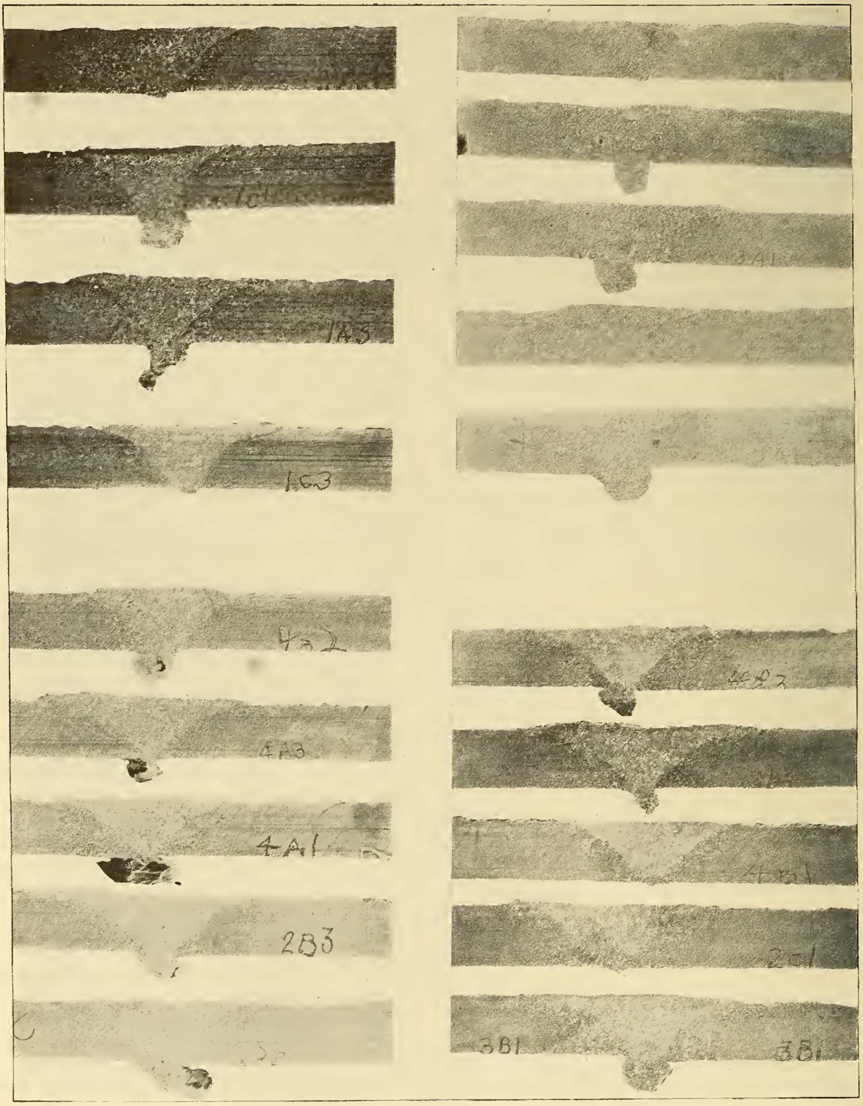

FIG. 66.—*Etched sections through welds*

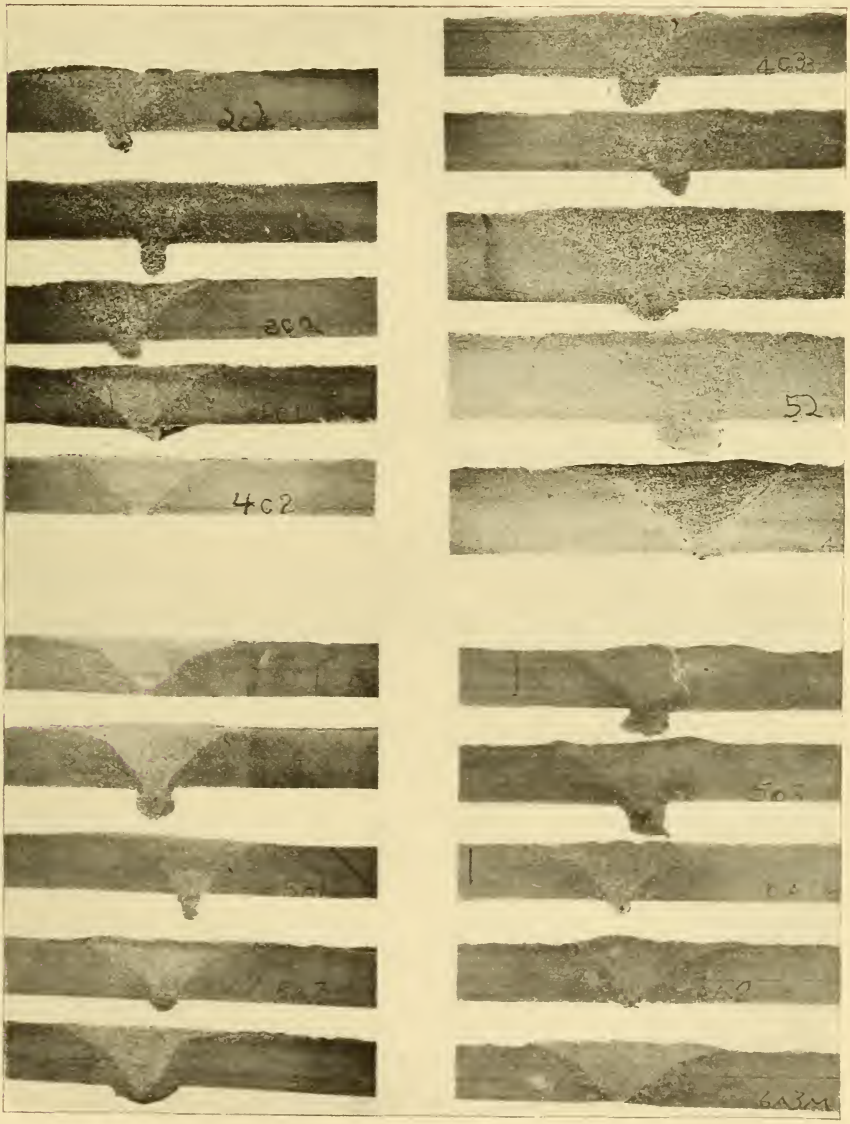

FIG. 67.—*Etched sections through welds*—Continued

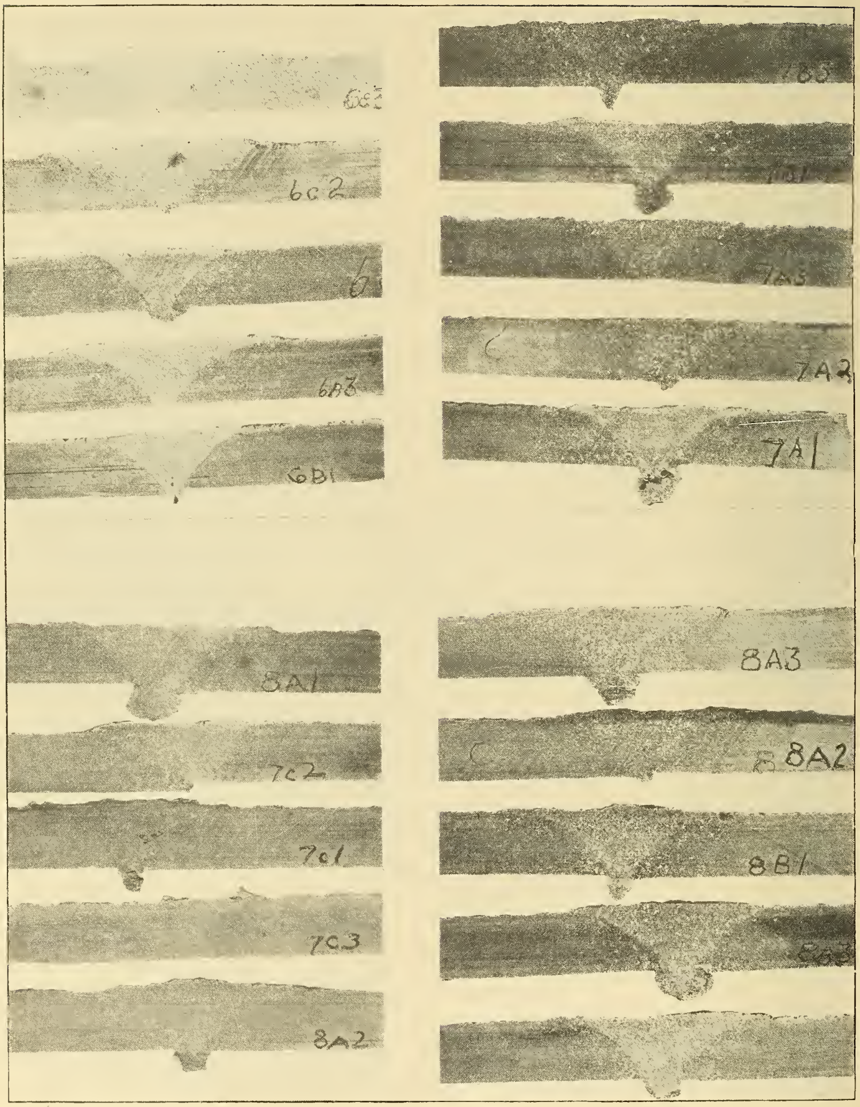

Fig. 68.—*Etched sections through welds*—Continued

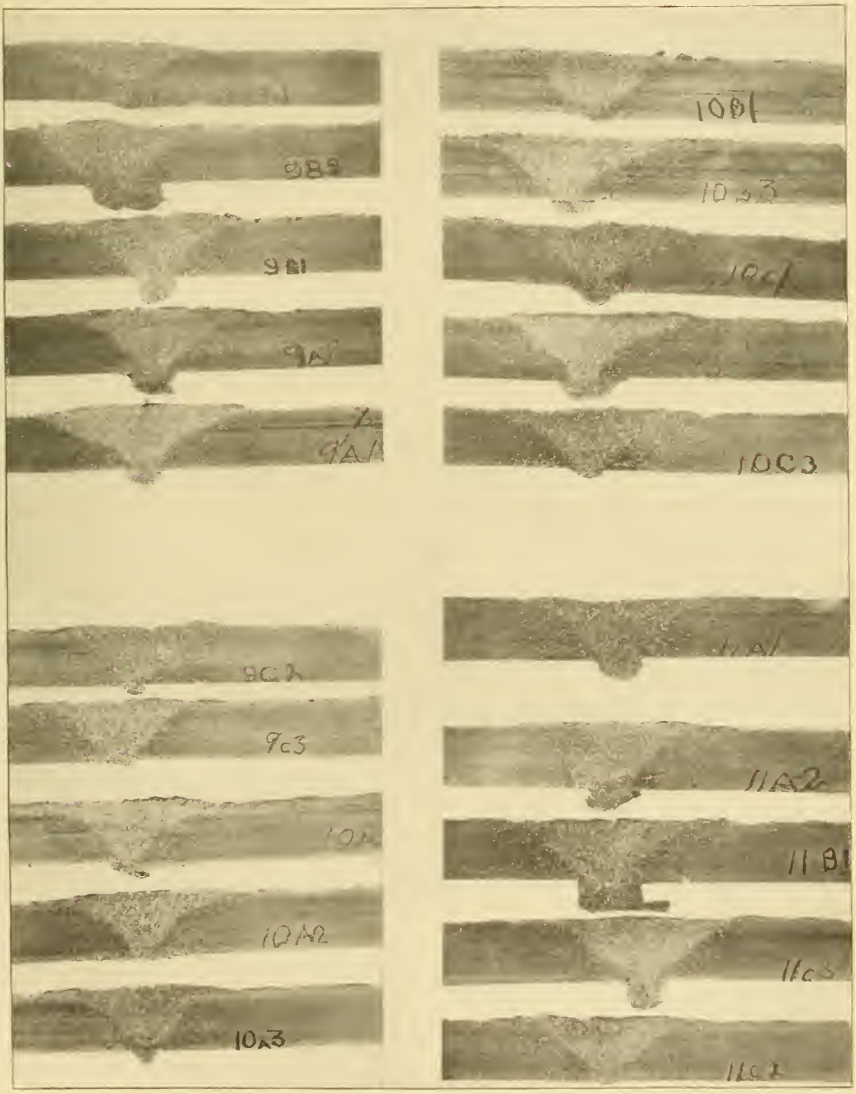

FIG. 69.—*Etched sections through welds*—Continued

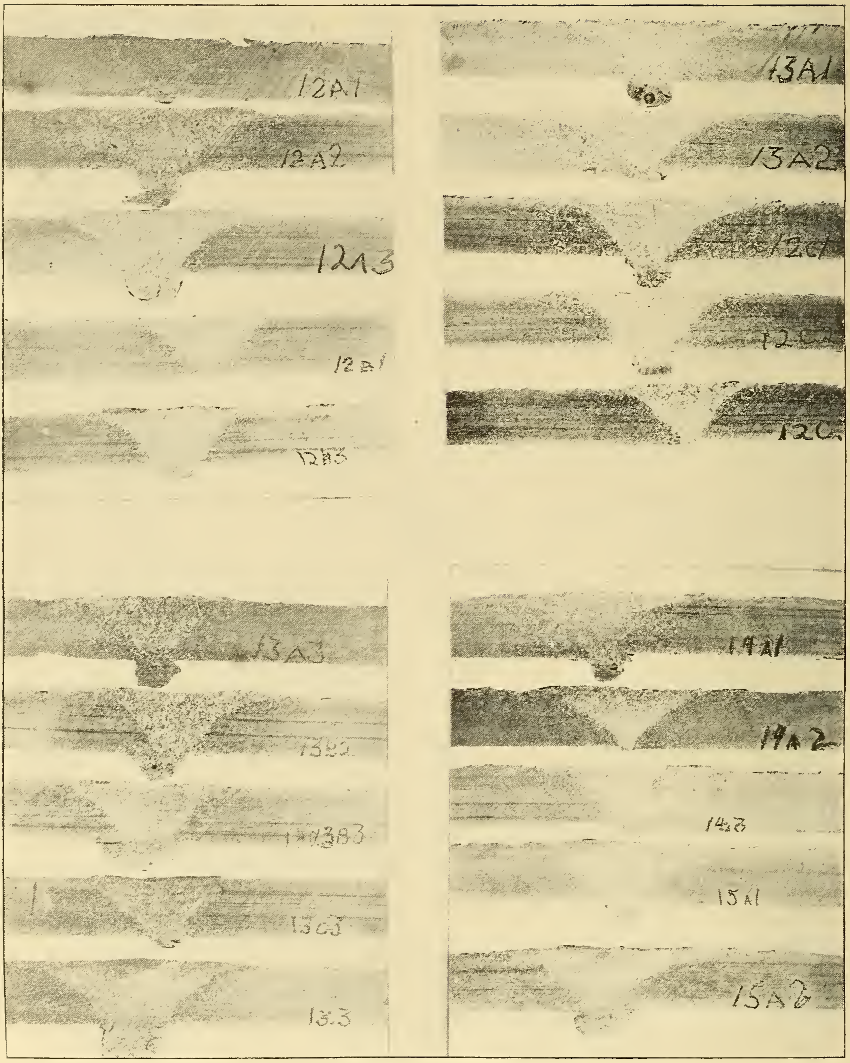

FIG. 70.—*Etched sections through welds*—Continued

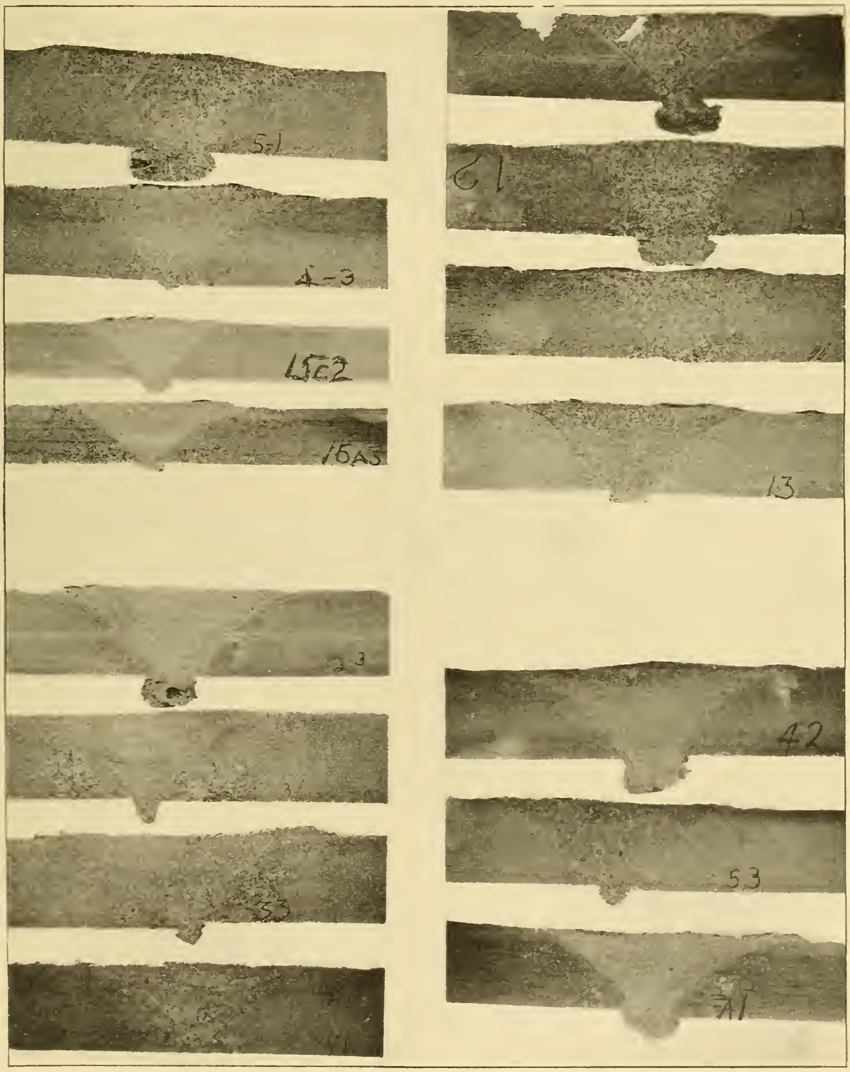

Fig. 71.—*Etched sections through welds*—Concluded

possibly this condition may be found to exist for metal of other thicknesses than those used in the tests.

6. That the maximum thickness of metal that may be economically cut with an oxyacetylene blowpipe of standard design when neither the material nor the oxygen is preheated and the cutting is done only from one direction is about 12 inches.

7. That cutting blowpipes, due to their incorrect design, are subject to the same flash-back troubles found in the welding blowpipes.

FOR THE WELDING BLOWPIPES.—1. That the blowpipes most subject to the so-called flash-back phenomena are those in which the oxygen is delivered at a pressure in excess of that at which the acetylene is delivered.

2. That all the blowpipes tested, including those in which the acetylene is delivered at an excess pressure as well as the so-called equal or balanced pressure blowpipes, are subject to flash-back phenomena on account of inherent defects in their design.

3. That the cause of the development of the conditions producing flash back is the setting up within the blowpipe tip and head of a back pressure which retards or chokes off the flow of one of the gases.

4. That this back pressure is the result of confining or restricting the volume flow of the issuing gases at the tip end.

5. That any cause tending to restrict the flow of the gases sets up a back pressure, which immediately causes a change in the amount of each gas delivered to the mixing chamber.

6. That a fluctuating gas volume ratio, due to restriction of volume flow, from whatever cause, prevents a blowpipe from maintaining constantly and at all times during operation the desired "neutral flame."

7. That a blowpipe that can not maintain under all operating conditions a neutral flame can not logically be expected to produce sound welds.

8. That all the blowpipes tested during this investigation, either through improper gas pressures or improper interior design or both are incapable of maintaining a neutral flame (constant volume gas ratio) under all conditions of restricted gas flow and are therefore incapable of producing sound welds where there is any liability of the gaseous products of combustion being momentarily confined, such as occurs in practically all welding operations.

9. That the ability of a blowpipe to consume an equal volume ratio of gases when burning freely and undisturbed in air is no criterion that it is capable of producing sound welds; that is, that it is not subject to detrimental fluctuations in gas ratio during a welding operation and therefore is capable of maintaining a neutral flame under all operating conditions.

10. That whether blowpipes of present designs will consume equal volume ratio of gases when burning freely and undisturbed in air depends on how nearly correct the operator sets the so-called neutral flame, and experience indicates that the average operator checks the acetylene gas flow too much and actually develops an oxidizing rather than a neutral flame.

11. That the question of the possible limiting strength and ductility or the efficiency of welds made by the oxyacetylene welding blowpipe must await the development of a more satisfactory instrument, and that having such an instrument there is no reason to believe that a weld of clean sound metal can not be made with assurance during any welding operation and that such welds will or can be made to possess the proper physical properties.

WASHINGTON, March 13, 1921.